PIBS 1319

AQUACULTURE WASTEWATER TREATMENT: WASTEWATER CHARACTERIZATION AND DEVELOPMENT OF APPROPRIATE TREATMENT TECHNOLOGIES FOR THE ONTARIO TROUT PRODUCTION INDUSTRY

DECEMBER 1990

Ontario
Environment
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MOE AQUACULTURE COMMITTEE RESPONSE TO "AQUACULTURE WASTEWATER TREATMENT: WASTEWATER CHARACTERIZATION AND DEVELOPMENT OF APPROPRIATE TREATMENT TECHNOLOGIES FOR THE ONTARIO TROUT PRODUCTION INDUSTRY"

The above referenced report submitted by Canadian Aquaculture Systems provides results of an extensive field study which examined fish production practices, culture facilities design, suspended solids settling behaviour, and critical design parameters of existing effluent treatment facilities, in an effort to identify those factors which most significantly affect effluent quality and management.

The consultant's conclusions and recommendations address suitable treatment technology, design requirements, management and operating principles to be applied at aquaculture facilities in order to minimize the loadings of suspended solids and total phosphorus in effluent discharged to a receiving water.

The conclusions and recommendations contained in Chapter 8.0 of the report are examined below and the Committee's position is provided.

8.1 Ontario Aquaculture Operations

The Committee concurs with the conclusions and recommendations listed in this section as a whole. It should be noted, that while feed-related factors were found to be subordinate with respect to pollution impact (8.1.7), they should not be discounted for their potential in the overall management of an aquaculture operation with the goal of minimizing effluent contaminant discharges. Several feed-related factors, such as reduced phosphorus content, were not included in the study and may play an important role in reducing contaminant discharges.

.../2

8.2 Effluent Treatment Design

8.2.1

Overflow rate was recommended as the basis for effective facility design. Specific design limits are listed. The Committee concurs with this recommendation and would add that other design considerations, such as flow through velocity and inlet and outlet design, which were addressed in the body of the report are also of importance in ensuring a treatment facility design that will be effective in reducing contaminant discharges.

The report also notes that with the recommended design limits that Total Phosphorus (TP) may marginally exceed the 0.10 mg/l compliance limit. While this may be occurring with several existing operations, the Committee believes that through measures such as improved feed formulations, which have reduced phosphorus content, and with improved overall facility management practices, that the TP compliance limit will be achieved consistently.

8.2.2 and 8.2.3

The Committee concurs with the recommendations.

8.3 Best Management Strategies

The Committee concurs with the conclusions and recommendations listed in this section as a whole. The conclusion that vacuuming of settled wastes is the most effective removal method (8.3.4) should also identify the importance of a regular schedule of cleaning in ensuring the overall performance of the treatment system. The appropriate cleanout frequency will be as required to satisfy the effluent limits, but can be expected to be approximately twice weekly. It should be noted that the dollar values listed in 8.3.6 are in 1990 dollars.

.../3

8.4 Enforcement of Ministry Guidelines

8.4.1

The current compliance limit contained in the guideline for Total Phosphorus (TP) is 0.10 mg/l except where the background level in a surface water supply exceeds 0.10 mg/l in which case TP shall not exceed the background concentration. Maintaining an absolute limit for groundwater supply systems reflects the Committee's position of not allowing the export of a poor quality water supply to other receiving waters. For surface water supply systems some of the background TP will be removed as a result of the treatment system, thus facilities will be able to operate and achieve the no net increase above background criterion. The position of no net increase when background concentrations exceed 0.10 mg/l is in keeping with Policy 2 from the Publication "Water Management - Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment", May 1984.

The Committee concurs that the solubility of phosphorus can affect the overall performance of the treatment system, and thus advocates a regular and frequent cleaning program. Additionally, the Committee concurs that the reduction of excess phosphorus in commercial feeds could reduce contaminant discharges.

8.4.2

The Committee does not concur. Environmental impacts due to aquaculture operations have been documented. As well, the potential for impacts in sensitive headwater areas is strong. Additional documentation of phosphorus loadings will be provided through the reporting requirements contained in Certificates of Approval.

8.4.3

The Committee concurs that research is required into the discharge of supernatant from manure storage lagoons, but would add that specific attention should be focused on the potential for impacts on groundwater quality.

.../4

8.4.4

The Committee concurs that a co-operative effort will best protect the environment. Consultation with industry organizations and other provincial agencies has been ongoing. The Committee does not concur with the recommendation to place the interim guidelines in abeyance, as this would allow uncontrolled development within the industry and would place the Ministry in a reactive position in dealing with environmental impacts. Through the use of the interim guidelines the Ministry is attempting to be proactive and prevent adverse impacts from occurring.

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AQUACULTURE WASTEWATER TREATMENT:

WASTEWATER CHARACTERIZATION AND DEVELOPMENT OF APPROPRIATE TREATMENT TECHNOLOGIES FOR THE ONTARIO TROUT PRODUCTION INDUSTRY

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Environmental Services
Water Resources
Ministry of the Environment

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EXECUTIVE SUMMARY

The environmental impact of intensive fish culture has long been discussed, however, implementation of economically feasible and effective technologies for wastewater treatment remains minimal on an industry-wide scale. The design of wastewater treatment units requires a fundamental understanding of all aspects of fish culture and wastewater engineering. This extensive field study examines fish production practices, culture facilities design, suspended solids settling behaviour, and critical design parameters of existing effluent treatment facilities, in an effort to identify those factors which most significantly affect effluent quality and management. The design of culture units and specific culture/management practices are the principal factors governing effluent water quality prior to treatment. Most interestingly, for a given volumetric flow of water, no difference was observed in the carrying capacity (kg fish/Lps) of different facility designs; however, water quality was found to vary quite significantly, suggesting that certain designs and/or management practices are much more polluting. Sedimentation practices (i.e. gravity settling) tend to be most widely applicable in intensive salmonid aquaculture; they require no energy input or specialized operating skills, are relatively inexpensive to install and operate, and can be easily incorporated into both new and existing facilities. A detailed overview of sedimentation design for fish culture units is included.

ACKNOWLEDGEMENTS

This study was developed and implemented through the co-operative efforts of the private sector, and the provincial and federal governments. Financial support for the investigation was provided by The Ontario Ministry of the Environment and The National Research Council of Canada.

Mr. Stew Thornley was responsible for co-ordinating the support of the Ontario Ministry of the Environment. His efforts led to the use of the OME laboratories in London for analysis of water quality samples collected during the field investigation. Mr. Dan Lynch (NRC) arranged for Industrial Research Assistance Program (IRAP-H) funding to support the field monitoring program. Mr. John McFarlan (OTFA) was responsible for aligning the co-operation of the Ontario Trout Farmers' Association and those individual aquaculturists who are not members of the association.

The comments and constructive criticism offered by the members of the Ministry of the Environment Aquaculture Committee have enhanced the quality and presentation of the final report. Mr. Keith Somers (OME, Water Resources Branch, Toronto) provided invaluable assistance with statistical analyses. Many thanks are extended to the private and government aquaculturists throughout Ontario who permitted us to visit their operations to obtain the water quality samples and information which we required.

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1.0 INTRODUCTION

1.1 Aquaculture in Ontario

Aquaculture began in Canada over 100 years ago with the controlled propagation of a variety of sport fish species for stock enhancement programs (MacCrimmon 1984). Such operations were predominantly hatchery operations designed to supplement the recruitment and survival of fry. It was not until the 1950s, with the culture of oysters and trout in British Columbia, that commercial production of fish for human consumption began.

In Ontario, commercial aquaculture commenced in 1962 and has grown at a rapid rate ever since. Moccia and Castledine (1987) have outlined this development in three major phases. The "Novice" phase (1962 - 1975) was characterized by low productivity. From 1975 to 1981, the "Skills Development" phase witnessed a large increase in the number of farms, the establishment of a domestic supply network, and the formation of the Ontario Trout Farmers' Association. Since the early 1980s, the "Industrialization" phase has seen the intensification of culture practices and the beginning of the Ontario Trout Producers' Co-operative. The latter was instrumental in opening up distribution channels into high-volume markets and, consequently, it induced many more farmers and entrepreneurs to establish fish farming operations.

Since the beginning of commercial aquaculture in the province, Rainbow Trout has been the only species cultured in economically significant quantities. Although Brook (Speckled) Charr and both Smallmouth and Largemouth Bass are also farm-raised, these species are generally cultured for stock enhancement purposes and are not cultured in large quantities in feedlot-type operations. Presently, there are about 227 private, community-run, and government aquaculture facilities in Ontario (UMA 1988). In 1988, the 120 commercial farms throughout the province produced approximately 1,830 tonnes (4 million pounds) of trout, and production is expected to double by 1995 (Moccia and Bevan 1989). Currently, the industry remains somewhat fragmented, with the majority of operations being only small-to medium-size and serving to supplement the income of traditional farmers (Stechey et al. 1987). Moccia and Bevan (1989) found that 25% of commercial farms produced less that 2 tonnes in 1988, 50% produced less than 9 tonnes, and 75% less than 23 tonnes.

1.2 Environmental Impact of Intensive Salmonid Aquaculture

In many types of commercial aquaculture, production practices must be highly intensive for an operation to achieve economic feasibility. In such systems, it is not unusual for the available water supply to be re-used in multi-pass facilities to attain the necessary production goals. Moreover, in aquaculture, there is a saying: "Fish don't pollute, but feed does!" As with all animals, feed is only partially utilized by the fish; the remainder is discarded into the water as soluble metabolic by-products and solid waste. Consequently, intensive culture practices can lead to substantial deterioration of water quality. Unlike the terrestrial farming of livestock, which often creates off-site pollution problems, unutilized feed and metabolic waste products excreted by the fish foul

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the water and, therefore, the system requires continuous flushing to maintain an acceptable culture environment (Wheaton 1977).

Nearly 20 years ago, Liao (1970a) stated that "The potential problem of pollutants discharged from a salmonid fish hatchery has long been overlooked. There is almost no literature on the subject." Today, however, the problem is well recognized and the issue of effluent quality has been a concern from an environmental perspective for many years. Aquacultural wastewater treatment is no longer viewed as an option in fish farming; it is necessary for the protection of the receiving water course and the assurance that water quality objectives are attained.

Nevertheless, while it is commonly accepted that rapid and gentle removal of the solid waste component of discharged effluent is essential, years of discussion and research have failed to produce appropriate technologies for effective and economical wastewater treatment at aquaculture facilities. In fact, Liao's statement, with minor modification, still applies today:

> The potential problem of pollutants discharged from a salmonid fish hatchery has long been *discussed*. There *remains* no *rationalized solution* on the subject.

Moreover, this problem is not limited to New Brunswick smolt production operations. In Aquaculture Magazine, Hopkins and Manci (1989) state that, industry-wide,

> "pollution-related problems in fish culture are on the rise. As the industry grows and expands, these problems will continue to intensify unless economically and scientifically sound solutions are discovered and applied."

Liao (1970a) classifies aquacultural waste products into three categories:

(1) chemicals and drugs employed for cleaning and/or control of diseases, parasites and aquatic weeds;

(2) bacteria and parasites which may be harboured in the facility and subsequently released; and,

(3) fish fecal matter and residual feed, and soluble metabolic products.

While the first two categories of pollutants are important to understanding the full impact of aquacultural discharges, for the most part they tend to occur relatively infrequently. Nevertheless, these issues must also be examined by the aquaculture industry -- ideally before they lead to problems similar to current concerns with respect to solids and nutrient discharges. In contrast, however, the discharge of fish fecal matter and residual feed is an ongoing occurrence at commercial, hobby, and R&D fish culture facilities. Moreover, since most salmonid aquaculture facilities are located on sites in the proximity of high-quality water resources, the solid waste component presents a serious pollution problem, especially when farm effluents are discharged to sensitive cold-water

receiving bodies. Conventional loadings of seven common fish farm pollutants are presented in Exhibits 1.1 and 1.2.

1.2.1 Suspended Solids Production in Intensive Salmonid Culture

Aquaculture-related pollution problems manifest themselves in various ways. The accumulation of solid matter on stream bottoms can be especially detrimental to aquatic environments. In fact, the Michigan DNR (1973) concluded that the total suspended solids load was the most significant problem caused by hatchery discharges. Since fecal and feed solids are predominantly organic matter, their oxidation depletes the dissolved oxygen concentration in the water and results in the release of dissolved nutrients. Moreover, these solid wastes support a diverse population of micro-organisms which also contribute to oxygen depletion, and which may be deleterious to other aquatic species. If left to accumulate to depths where bottom layers become anaerobic, noxious gases and other toxic compounds can form. Samuelsen et al. (1988) found that the gases generated from fish farm sediment deposits consisted primarily of methane (70-90%), carbon dioxide (10-30%), and hydrogen sulphide (1-2%), all of which are toxic to fishes and other aquatic organisms.

Relative to phosphorus, waste solids production in intensive fish culture is less complex to model, and solids are substantially simpler to remove from discharged effluent. Due to periodic changes in feed formulations based upon feed ingredient costs, however, waste solids production is not necessarily predictable. Nevertheless, industry average production rates have been established for intensive trout culture which are sufficiently accurate for modelling.

Merican and Phillips (1985) report no significant correlation ($P>0.05$) between TSS output and fish size, and conclude that feeding rate, rather than fish size, is the primary determinant of solid waste production. Depending on feed composition and digestibility (efficiency of utilization), waste solids production varies between approximately 200 kg and 1000 kg per metric tonne of fish produced (Westers 1989). A number of researchers suggest that 300 grams of waste solids per kilogram of feed added to the system is an acceptable industry average (Willoughby et al. 1972; Mudrak and Stark 1981; Zeigler 1988). This production rate is confirmed by Cho et al. (1985), who found waste solids production to range between 200 to 400 grams per kilogram feed. Westers (1989) indicates that levels below 200 gTSS/kg feed are unrealistic in commercial culture settings and that levels above 450 gTSS/kg feed are infrequent since they tend to be indicative of poor feed utilization and/or feed wastage. Moreover, since feed is the largest single cost factor in commercial trout culture, the latter quickly becomes uneconomical. For modelling purposes, a solids production rate of 300 grams TSS per kg feed is conventionally applied (Exhibit 1.1).

1.2.2 Phosphorus Production in Intensive Salmonid Culture

The addition of phosphorus to aquatic habitats can present serious, long-term pollution problems. Fortunately, from a biological productivity perspective, inorganic orthophosphate is the only form of phosphorus of

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significance (Wetzel 1975), and the phosphorus component in fish feed which ultimately ends up in the receiving body of water is principally organic phosphorus bound within the solid waste particles (Persson 1988). As such, it is biologically unavailable in the water column.

Nevertheless, chemical and biological reactions can act to liberate phosphorus from bound particles, thereby enhancing primary productivity and eutrophication. In the water column, an exchange equilibrium is established between phosphorus in sediments and the water. Under aerobic conditions, this equilibrium is largely uni-directional toward the sediments. Once the sediment layer becomes sufficiently thick (deep), such that diffusion of oxygen to lower layers becomes limiting, anaerobic conditions develop. In the absence of oxygen, the equilibrium shifts toward the water column due to changes in redox conditions, resulting in the release of biologically available phosphorus compounds. Phosphorus mobilizing bacteria are also present, especially in highly organic sediments such as fish culture wastes, and serve to increase the pollution impact of phosphorus, although their impact is generally about 1/20th that of anaerobic chemical reactions (Wetzel 1975; Sondergaard 1988).

This biologically available fraction of phosphorus (and to a lessor extent, nitrites and nitrates) in fish farm discharges, contributes to the enhancement of primary productivity (i.e. increased populations of micro- and macro-algae), thereby promoting eutrophication of the receiving body of water (Trojanowski et al. 1985; Persson 1988). In Ontario, the Ministry of the Environment (1982) observed that the aquatic environment was substantially impaired in streams downstream from discharges from trout farms as compared to sites immediately upstream from the farms. Detrimental effects were principally related to increases in the total number of benthic organisms, especially *Chironomidae* (midge) and *Simuliidae* (black flies), the stimulation of luxuriant plant and algal growths, and the accumulation of organic solids on stream bottoms. The Michigan Department of Natural Resources (1973) studied water quality below 9 salmonid fish culture facilities in the state and discovered downstream increases in the concentrations of biochemical oxygen demand (BOD), suspended solids, organic nitrogen, ammonia nitrogen, soluble ortho-phosphate, and total phosphorus. Liao (1970a) also reports similar upstream-downstream changes at aquaculture effluent discharge sites in Washington state.

Salmonid fishes have 3.8 to 4.5 grams of phosphorus per kilogram body tissue; the accepted average being 4.0 grams P/kg tissue or 0.4%. Nevertheless, the dietary requirement for phosphorus is generally 0.7 to 0.8 percent feed weight, in spite of research results which indicate that experimental diets having phosphorus concentrations as low as 0.4% produce no detrimental effects to production and growth (Ketola 1985; Eskelinen 1986; Wiesmann et al. 1988). Many commercial diets, however, have phosphorus levels ranging between 1.1% and 1.8%. This excess phosphorus ultimately ends up in the receiving body of water since it cannot be utilized by the fish.

Merican and Phillips (1985) found that an average of 65.9% of dietary phosphorus is discharged in the solid fecal waste. Not all of this discharged phosphorus remains bound, however. EIFAC (1972) reports that up to 32% of the particulate phosphorus is solubilized within 2 days of discharge. Alternatively, field data show that, on average, 30% to 60% of all phosphorus discharged from

salmonid fish culture operations is permanently retained in the sediment fraction of the solid waste (Persson 1988). Variability is due to the feed brand and specific feed ingredients. For instance, phytin, a phosphorus compound in plant proteins, is poorly absorbed by fish, yet it is frequently included in fish feeds. Other sources of phosphorus, such as defluorinated rock phosphate, are better utilized by salmonid fishes and are less polluting (Ketola 1985). Based on usual ingredients, commercial diets tend to contain excessive quantities of phosphorus which are not required for optimum performance (Wiesmann et al. 1988).

The figures presented in Exhibit 1.3 simplify the utilization of phosphorus by salmonids to illustrate the potential pollution impact of excess dietary phosphorus. The numbers reveal that effluent phosphorus levels increase substantially with increased dietary phosphorus since fish have a limited phosphorus uptake capacity, which does not change with dietary level. Notice that a change in dietary phosphorus concentrations from 0.7% to 1.6% increases total discharged phosphorus four-fold.

Westers (1989) suggests that the average discharge of phosphorus from salmonid culture operations ranges between 1.5 and 25 kg P per metric tonne of fish produced. Castledine (1986) provides factors used to determine waste phosphorus production in intensive rainbow trout culture facilities. He indicates that, for every kilogram of feed added to the system, 5.4 grams of settleable and suspended phosphorus and 2.2 grams of dissolved phosphorus are discharged in the production effluent; a total of 7.6 grams of phosphorus per kilogram feed. The proportion of TP to DP is 71:29. Cho (1990) and Ketola (1989) suggest that 9 grams of phosphorus per kilogram of feed may be more a appropriate factor, and that the breakdown between solid and soluble forms approximates 67:33. Cho further adds that, at a minimum, 25% of all phosphorus in the effluent will be dissolved in solution. Castledine's factors are most frequently applied for effluent modelling (Exhibit 1.1).

Therefore, the production of pollutants in salmonid aquaculture is directly related to the input of feed to the culture system and can be estimated using the accepted feed factors as described by Castledine (1986), and presented in Exhibit 1.1. It should be noted, however, that feed quality, daily operations (i.e. feeding, cleaning, etc.), culture practices (i.e. stocking densities, water flow rates, general management techniques, etc.), and seasonal variation in standing crop biomass create fluctuations in the actual amount of wastes produced. Although suspended solids and nutrient concentrations in salmonid fish culture effluent are relatively dilute (see Exhibit 1.2), long-term cumulative problems may develop in receiving waters due to the high flow rates required by salmonid fishes (Liao 1970a).

1.3 Project Purpose and Objectives

Consequently, in view of the wastes generated in salmonid fish culture, aquacultural effluents can potentially violate several of the Provincial Water Quality Objectives (Ministry of the Environment 1984) and/or specific *interim* guidelines established for the Ontario aquaculture industry:

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1) Average effluent concentrations exceeding 10 mg total suspended solids per litre and/or 0.10 mg total phosphorus per litre are above interim compliance limits and are, therefore, deemed to be detrimental to receiving bodies of water.

2) The mass of solids produced may settle to form objectionable deposits in the receiving water course.

3) Dissolved phosphorus and nitrogen compounds may contribute to undesirable aquatic life or result in the dominance of nuisance species.

4) To a lesser extent, floating bacterial and/or algal mats and scum may become a nuisance.

5) If poorly designed settling ponds are used (as is currently the case at several operations), long detention times may cause warming of the discharged effluent during summer months, which may create a barrier to the migration of fish and aquatic life in the mixing zone of the receiving body of water.

Therefore, an effective means for reducing the solids content of the discharged effluent is necessary; however, the high volumetric flow rate, and the relatively dilute concentration of pollutants in the effluent, impose a unique constraint on effluent treatment. Westers (1989) reports that the concentration of phosphorus discharged from tertiary sewage treatment lagoons may be as much as ten times greater than that in untreated fish hatchery effluent. The total volumetric flow from salmonid hatcheries compounds the impact, however. Solbe (1988) suggests that the impact of <u>untreated</u> effluent from 1000 kilograms of fish is equivalent to the daily discharge of <u>treated</u> sewage from a city of 300,000 people. Consequently, treatment technologies must be highly efficient, yet they must also be economically feasible to install and operate (Liao 1970b).

The uniqueness of most fish culture operations has meant that standardized effluent treatment technologies have not been developed. Rather, treatment facilities tend to be custom-made for individual operations (Lindqvist 1986). Although custom design may continue to be the norm in this industry, with its diversity of facility designs and culture practices, a need nevertheless exists for the development of standardized design protocol.

Consequently, the purpose of this investigation has been to conduct applied research to identify standardized and cost-effective techniques for the design and implementation of appropriate wastewater treatment technologies and operating practices for both new and existing fish culture facilities in the Province of Ontario. Within the scope of this investigation, the following objectives have been targeted:

1) Characterization of fish farming wastes on an industry-wide scale.

2) Evaluation of existing effluent treatment facilities.

3) Identification of primary constraints relating to the high-volume, low-concentration nature of fish farm effluents and identification of appropriate technologies for aquaculture wastewater treatment.

4) Assessment of the economics and cost structuring of aquaculture wastewater treatment facilities, including capital and operating expenses.

5) Assessment of the suitability of the current "Interim Environmental Guidelines for Salmonid Aquaculture Facilities in Ontario."

Exhibit 1.1:
Accepted factors used to determine waste production from salmonid fish culture facilities based upon feed consumption.

Pollutant	Factor (x feed weight)[1]
Total Settleable & Suspended Solids	.300[2]
Settleable & Suspended Phosphorus	.0054
Dissolved Phosphorus	.0022
Total Phosphorus	.0076
Settleable & Suspended Nitrogen	.0064
Dissolved Nitrogen	.0317
Ammonia	.0383

Source: Castledine (1986)

[1] Factors will vary with changes in dietary efficiency. These factors assume dry feed (10% moisture) with an average digestibility of 80% and a Food Conversion Ratio = 1.2

[2] Westers (1989)

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Exhibit 1.2:
Average increase in pollutant concentrations at salmonid fish culture facilities during normal operations. All units in mg/L.

Pollutant	Average Increase	Range
BOD	5.36	0.12 - 36.5
Ammonia	0.532	0.00 - 2.55
Nitrite	1.676	0.045 - 3.1
Phosphorus	0.077	0.01 - 0.26
Suspended Solids	7.0	0.0 - 55
Settleable Solids	3.5	0.0 - 35

Source: Liao (1970a)

Exhibit 1.3:
The fate of dietary phosphorus based upon % phosphorus in feed, and assuming that fish utilize 0.4% phosphorus by body weight. This oversimplifies the issue, however, it is intended to illustrate the fate of excess dietary phosphorus.

% P in Feed	kg P/1000 kg Feed	kg P Retained by Fish	% P Retained by Fish	kg P Discharged in Effluent
0.7	7.0	4.0	57.0	3.0
1.1	11.0	4.0	36.0	7.0
1.6	16.0	4.0	25.0	12.0

2.0 TECHNOLOGIES FOR AQUACULTURE EFFLUENT TREATMENT

Due to the high volume of process water associated with intensive salmonid fish culture operations, and the concomitant low concentration of particulate and dissolved pollutants, effluent treatment practices are generally limited to primary treatment technologies; that is, the removal of particulate matter (Persson 1988). Secondary (i.e. biological filtration, aerated lagoons, carbon absorption) and tertiary (i.e. chemical coagulation, nitrification-denitrification, ion exchange, etc.) treatment technologies have received only limited use in aquaculture, and tend to be limited to highly-specialized applications.

The removal of solid material from wastewater streams and the selection of appropriate treatment technologies is governed by (1) particle size, (2) specific gravity, and (3) strength, or shear resistance, of the particulate matter. An initial requirement, therefore, in selecting an appropriate solids separation technique for any application, is identification of the properties of the material to be separated.

Wastewater solids are routinely classified into four categories, based upon particle size: soluble (<0.001 μm); colloidal (0.001 - 1.0 μm); supra-colloidal (1.0 - 100 μm); and settleable (>100 μm). The total suspended solids (TSS) component of a wastewater stream is determined by filtration of a sample of the wastewater through a 0.45 μm membrane filter, and measurement of the dry weight of the sample in mg/L. Settleable solids are further defined as that portion of the TSS which will settle, in quiescent conditions, within one hour due to gravity alone (Sundstrom and Klei 1979).

Numerous technologies, most of which have originated in municipal and/or industrial wastewater treatment applications, have been applied in aquaculture for solids control. The UMA Engineering Ltd. report (1988) describes the use of several of these methods in fish farming, including gravitational separation, screening, and filtration, among others. Consequently, similar descriptions will not be presented here. Alternative technologies, including peat bed filtration, flocculation through addition of coagulants, and nutrient removal via plant biomass uptake, are described by Parjala (1984). Stechey (1987) discusses the use of static screen, vibrating screen, centrifugal screen, micro-screen, and compact sedimentation units.

Peat bed filtration is conducted in earthen ponds having a 30 - 50 cm thick layer of peat overlaid on a gravel percolation bed. While the specific absorption of peat varies with the species of peat, its level of humification, and various physical and chemical properties, a rule of thumb states that up to 200 grams of phosphorus can be removed per cubic meter of peat. In spite of its capacity for phosphorus absorption, commercial-scale application is limited to only the smallest farms due to total flow limitations. Similarly, coagulation also tends to be inefficient for aquacultural application, again due to the high volume, low concentration nature of the wastewater stream. Moreover, the cost of chemical coagulants would be relatively high and large contact chambers would be required (Parjala 1984).

Static screens offer the advantages of high volumetric capacity, compact size and portability, relatively long screen life, production of a relatively concentrated solids fraction, and the addition of dissolved oxygen to the wastewater stream. In aquacultural applications, however, the specific gravity of the solids to be clarified is often too low to adequately permit their collection and discharge from the units. Moreover, most high-volume static screens require a pressurized feed source, resulting in an added energy component (Dorr-Oliver 1982). As well, on-site testing with low-head gravity-feed screens has revealed that undigested plant materials (presumably fibre from feed ingredients) and the relatively sticky fish fecal material cause blinding of the screen, resulting in the need for frequent cleaning (Stechey 1987).

Consequently, it is generally agreed that, for efficient and effective removal of solids from fish farm effluents, most existing filtration and screening technologies tend to be impractical from either a functional and/or economical approach. Notwithstanding that some commercially available treatment units have an application in specific aquaculture operations, sedimentation practices (i.e. gravity separation) tend to be most widely applicable in commercial salmonid culture. Sedimentation basins require no energy input, are relatively inexpensive to install and operate, require no specialized operational skills, and can be easily incorporated into both new and existing facilities. Moreover, they tend to produce acceptable effluent quality.

3.0 SEDIMENTATION TECHNOLOGIES FOR AQUACULTURE WASTEWATER TREATMENT

3.1 Fundamental Concepts of Sedimentation

When a liquid containing particulate matter is placed into a relatively quiescent state, those particles having a specific gravity greater than that of the liquid begin to settle. This principle has been applied for generations as a means of clarifying wastewater streams. Depending upon particle size and density, and the physical characteristics of the waste and the wastewater medium (water), the sedimentation process can be defined as either discrete (Class I), hindered or flocculent (Class II), zone (Class III), or compression settling (Class IV). These processes are defined in Exhibit 3.1.

A rule of thumb suggests that, at total suspended solids concentrations less than approximately 500 mg/L (0.05% solids), sedimentation is typically discrete (Camp 1946). Discrete settling particles maintain their size and shape in a dilute suspension, and have little tendency to adhere upon collision. Each discrete particle has a constant settling velocity, which is independent of that of other particles. Flocculation tends not to occur due to the remote likelihood of chance collisions between particles in such dilute concentrations. Therefore, in salmonid fish culture effluents, it is reasonable to assume that settling is discrete.

Exhibit 3.1:
Suspension classes and their settling characteristics.

Class I Suspensions - Discrete

Definition: Dilute suspensions of non-flocculent particles that settle out of suspension unhindered by the presence of other particles.

Behaviour: Sedimentation rate is governed only by the surface area of the sedimentation basin.

Class II Suspensions - Flocculent

Definition: Dilute suspensions of flocculent particles which, upon collision, coalesce and settle at rates greater than did the parent particles.

Behaviour: Sedimentation rate governed by (1) surface area of sedimentation basin, (2) concentrations of suspensions, and (3) depth of basin.

Class III Suspensions - Zone

Definition: Suspensions of high concentration in which particles settle in a fixed position relative to each other in a regime referred to as hindered or zone settling. Particles may be flocculent or non-flocculent.

Behaviour: Sedimentation rate governed by (1) surface area of sedimentation basin, (2) concentration of suspension, (3) solids loading, and (4) depth of basin.

Class IV Suspensions - Compression

Definition: As particles accumulate in layers on the bottom of the basin, each layer of solids provides support for those layers above and the solids undergo compressive stress which compacts the layers further.

Behaviour: Sedimentation has already been achieved prior to this stage; concentration of the settled solids is governed by (1) the sludge depth, and (2) the retention time in this compressive zone.

Source: Adapted from Sundstrom and Klei (1979); Rich (1980)

Under the force of gravity, a particle accelerates downward through the water column until the gravitational force comes into equilibrium with the opposing frictional fluid drag force. When these opposing forces become balanced, the particle settles at a uniform velocity, which is referred to as the terminal settling velocity (Vs).

All continuous flow settling basins are comprised of four zones according to function (Exhibit 3.2). The inlet zone serves to uniformly distribute the suspension over the entire cross-section of the basin. Sedimentation occurs in the settling zone and, upon removal from the water column, the solids accumulate in the sludge zone. The clarified liquid is generally collected over the entire cross-section of the basin at the outlet zone and is discharged.

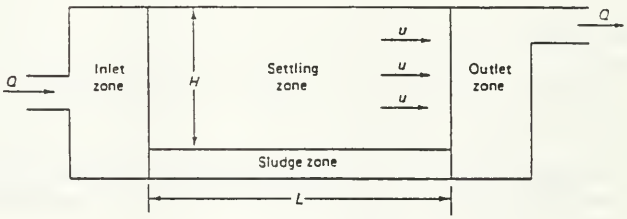

Exhibit 3.2: Four principal zones of a rectangular continuous flow sedimentation basin.

Sedimentation theory is most easily defined using an "ideal basin," for which the following assumptions apply:

(1) the direction of fluid flow is horizontal and the fluid velocity is constant at all points in the settling region;

(2) the concentration of suspended particles of each size is uniformly distributed over the vertical cross-section of the tank at the inlet end; and,

(3) all particles which settle to the basin floor remain permanently removed from the suspension.

In a rectangular ideal basin, the settling paths of all discrete particles are straight lines defined by the vector sum of the horizontal velocity component (U) due to fluid flow across the basin and the vertical settling velocity (Vs) of the particle due to gravity (Exhibit 3.3).

All particles with the same settling velocity will move in parallel paths. Under ideal conditions, a particle which starts at the top of the inlet zone and settles to the tank floor at the junction of the outlet zone during its theoretical detention period represents the tank discharge per unit surface area. This is defined as the tank overflow rate, which represents the unit volume of water flow per unit time divided by the unit area of the settling basin (Vo = Q/A); it is the average upflow velocity of the basin.

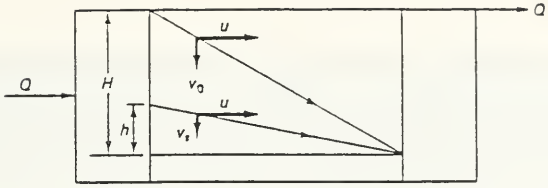

Exhibit 3.3: Settling paths of discrete particles in a rectangular sedimentation basin.

Any particle with a settling velocity (Vs) greater than the overflow rate (Vo) will settle out of suspension. Other particles, for which Vs < Vo, will be removed in the ratio Vs/Vo, depending upon their vertical position in the tank at the inlet (Hazen 1904). This fractional removal (Fx) is defined by the equation:

$$Fx = \frac{Vs}{Vo} = \frac{Vs}{Q/A}$$

The settling velocity analysis of a suspension may be presented as a cumulative distribution curve (CDC), with the vertical axis (Cr) representing the fraction of particles (f_o) in the suspension with settling velocities less than the corresponding settling velocity on the horizontal axis. [Note: This concept is applied in the settling curves for those farms included in the study; see Exhibit 4.7]. The fraction of particles removed completely then is equal to 1 - f_o; (i.e. those with Vs > Vo). The fractional removal of those particles with Vs < Vo is defined by the integral:

$$\int_0^{f_o} \frac{Vs}{Vo}\, df$$

The overall removal (F) of particles in suspension in an ideal basin is defined by the sum of the terms for settling velocities greater than and less than Vo, the tank overflow rate:

$$F = (1-f_o) + \frac{1}{Vo} \int_0^{f_o} Vs\, df$$

Therefore, the removal of suspended matter by sedimentation in an ideal basin is a function of the basin surface area and is independent of tank depth. Moreover, removal is a function of the overflow rate (Vo) and, for a given discharge, is independent of retention time.

3.2 Factors Influencing the Design of Sedimentation Basins

Sedimentation processes in actual basins are much more complex than the process described for an ideal basin. In an actual tank the behaviour of the settling particles is altered by turbulence and scour, which tend to re-suspend particles; and by velocity gradients, density currents and short-circuiting, which give rise to mixing and reduced removal efficiency.

3.2.1 Tank Velocity, Turbulence & Scour

In an ideal basin, the sedimentation of discrete particles is a function of overflow rate, and is independent of tank depth and retention time. In theory then, economics would suggest the use of infinitely shallow basins. Real basins, however, are restricted to minimum tank depths based upon the maximum allowable tank velocity (Uc) that can be maintained without excessive scour. In any basin of fixed dimensions, and for a given overflow rate, the tank velocity varies inversely with tank depth.

Unlike ideal basin theory, tank velocity is not uniform over the entire cross-section of the basin. Due to boundary layer drag forces, horizontal fluid flow is quickest in the centre of the tank near the surface, and slowest near the tank walls and floor. Even in the best designed settling basins, the Reynold's number (Re) will approximate 2×10^3 to 2×10^4, however, laminar flow conditions exist at $Re \leq 1500$ to 2000. Therefore, flow in settling basins is typically in transition or turbulent, which results in the rapid and continuous mixing of the fluid.

Since most particles remain undisturbed once they settle to the floor of the basin, the effect of turbulence is limited to a delay in the sedimentation process. This can be compensated for by lengthening the sedimentation basin in accordance with the turbulent flow characteristics. In general, since an increase in tank velocity results in increased turbulence, faster flowing tanks must be longer, or of greater diameter, than slower flowing tanks to comparably clarify the same wastewater stream.

Therefore, to achieve the efficiency of removal projected by theoretical basin design, it is necessary to compensate for turbulence by increasing the surface area of the settling basin. Compensation can be readily achieved by applying the concepts presented by Fair and Geyer (1958). Using ratios based upon sedimentation theory, a table of scale-up factors was compiled to enable designers to compensate for turbulence by adjusting the overflow rate in the principal design equations (Exhibit 3.4).

For example, assume that one is working with a settling basin of "good" design (i.e. proper inlets, outlets, flows, area, etc.), and that a design overflow rate of 40 $m^3/m^2/d$ (0.046 cm/s) has been applied and, furthermore, that this overflow rate is projected to yield 75% solids removal. The data in Exhibit 3.4 indicate that, in reality, the performance overflow rate is equal to 68 $m^3/m^2/d$ (0.079 cm/s); i.e. 40 x 1.7. Consequently, the performance efficiency will be less than the design efficiency; the extent of the reduction being dependent on the shape of the solids settling curve. The net result is a

reduced, but more accurate calculation of the removal efficiency of the basin. When applying these scaling factors, however, the characterization of basin performance necessitates judgmental assessment, based upon the net sum of all design considerations for both new and existing basins.

Exhibit 3.4
Ratios of required-to-theoretical surface areas of settling basins and of actual-to-theoretical settling velocities of particles at different removal efficiencies.

Basin Performance	Removal Efficiency (%)					
	70	75	80	85	90	95
Very Good	1.3	1.5	1.8	2.2	2.7	3.6
Good	1.4	1.7	2.0	2.5	3.2	4.8
Poor	1.7	2.0	2.5	3.2	4.4	6.9
Very Poor	2.3	3.0	4.0	5.9	10	19

Source: Adapted from Fair and Geyer (1958)

The re-suspension of settled particles by shear forces generated along the sludge surface by the horizontal flow of water through the basin is termed scour. Scour reduces sedimentation efficiency by stirring up the settled particles and reintroducing them to the water column. Camp (1946) defined the critical flow velocity (Uc) necessary to initiate scour of settled particles:

$$Uc = \sqrt{\left(\frac{8B}{f}\right)(g)(s-1)(D)}$$

where:
- Uc = critical scour velocity (m/s)
- B = constant = 0.06
- f = friction factor (approx. 0.024)
- g = gravitational acceleration (m/s^2)
- s = specific gravity of particles (approx. 1.005)
- D = mean particle diameter (m)

From this equation, it is evident that the critical flow velocity for commencement of scour is independent of tank size and depth. The governing factors are the friction factor and the mean size and specific gravity of the particles. For aquacultural waste solids ranging from 0.25 to 1.5 mm in diameter, approximate scour velocities equal 1.6 to 3.8 cm/s. This is in

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agreement with Parjala (1984) who recommends a maximum horizontal fluid flow rate of 2 - 4 cm/s in aquacultural settling basins. Conversely, Boersen and Westers (1986) concluded that horizontal flow velocities between 10 and 40 cm/s are required to prevent fecal and waste feed solids from settling in production tanks.

Dobbins (1944) determined that since solids removal is not independent of tank depth as indicated in ideal settling theory. The effect of depth is, nevertheless, quite small. On average, a 50% reduction in depth will result in approximately only a 5% decrease in removal of discrete particles. A 50% decrease in volume due to reduced depth, however, can be compensated for by a 5% increase in volume via increased surface area (Camp 1946). Thus, as economy dictates, the tank depth should still be maintained as shallow as possible, provided that scour-related problems do not arise.

3.2.2 Short-Circuiting & Tank Stability

Fluid flow through an ideal basin approximates plug flow, which means that there is no variation of lateral velocity over the cross-section of the tank. That is, a cross-section of water entering the settling zone from the inlet zone travels as a solid body throughout the length of the tank. Displacement is steady and uniform, and each unit volume of fluid is detained for the theoretical retention time of the basin, $R_t = Vol/Q$.

In reality, however, a portion of the flow exits from the tank after a shorter interval than the theoretical retention time while some of the water is retained longer. Short-circuiting is inherent to all tanks due to varying tank velocities in different stream paths caused by thermal-, density-, eddy- and wind-induced currents.

When the velocity of water entering the basin is too great, eddy currents are established by the inertia of the flowing water and mixing results. In large basins with long retention times, non-uniform heating of the water by the sun can result in vertical convection currents. Density currents typically occur when fluids of differing densities are combined in a quiescent tank or pond. The heavier fluid settles to the bottom of the basin and flows quicker than the lighter, top fluid. Fluid density differences may result from differences in temperature (solar heating), salinity, or suspended solids concentration. In most settling basins, however, fluid flow is generally sufficiently turbulent to disrupt density currents.

Wind shear over large tanks and ponds can create substantial surface currents which cause serious short-circuiting. The surface drift current is an almost constant ratio of the wind speed at 10 metres and this ratio varies minimally between researchers, and with Reynold's number (Plate 1970). A value of 1% to 3% of the 10 metre sustained wind speed is typical. Therefore, a wind speed of only 180 cm/s (approx. 6.5 km/hr) can induce a surface current with a speed of approximately 3.6 cm/s, which is of similar magnitude to conventional tank velocities.

Short-circuiting can also result from the presence of dead zones in a settling basin, which most commonly result from improper design of inlet and outlet structures (see Section 3.2.3). Dead zones are regions within a basin in which the liquid plays little or no part in the displacement through the tank. In fact, this occurrence can be readily observed on inappropriately designed basins during winter months. Where water flow is slowest (usually around pond edges or behind baffles and booms) the surface of the basin freezes over. Where flow is swift (such as along the direct line between point source inlet and outlet pipes), open water remains. This results in an effective tank volume, and area, which is less than actual tank dimensions. Consequently, a percentage of the influent stream passes through the basin in a shorter time than the theoretical detention time while some water remains in the basin for a longer time.

Thus, the net effect of short-circuiting on sedimentation processes is reduced efficiency. The influent flow rate to any settling basin is tuned to the basin overflow rate (Vo) and is relatively constant; however, short-circuiting streams of quicker flow have an overflow rate which is greater than the design rate. As a result, any particles in that stream having a settling velocity less than the stream overflow rate, but greater than the basin overflow rate, will not settle as they otherwise would have. Conversely, slow moving or stagnant areas must also exist, which further reduce the effectiveness of the settling process. Control of short-circuiting, therefore, is dependent upon dissipation of inlet velocity, protection of basins from wind shear and uneven heating, and reduction of density currents. Foremost, however, proper inlet and outlet design is critical for minimizing short-circuiting in settling basins.

3.2.3 Inlet & Outlet Design Considerations

As discussed, improper inlet and/or outlet design can result in short-circuiting and reduced sedimentation efficiency. Placing a single pipe at each end of a basin is the simplest design for inlet/outlet structures and, unfortunately, it is perhaps the design most frequently used in aquaculture today. This type of point-source inflow and outflow produces extremely poor flow characteristics for sedimentation. Short-circuiting is severe as the influent stream flows directly through the basin, at high velocity, toward the discharge pipe. Consequently, a large portion of the fluid passes through the basin in a matter of minutes, although the theoretical detention period may be a matter of hours. To be effective, the design of inlet and outlet structures must address the specific function and constraints of each process.

Inlet Design. When designing inlet structures, Ingersoll et al. (1956) suggest that the following factors must be considered:

(1) The influent stream should be introduced evenly across the entire cross-section of the settling zone.

(2) All flow through the settling zone should begin in even, horizontal paths.

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(3) The influent velocity to the settling zone should be slow enough to prevent excessive turbulence and mixing.

The influent to a settling basin usually flows through a pipe or channel which is smaller in cross-section than the basin. The flow, therefore, must diverge upon entering the inlet zone, often producing separation and turbulence in the process. A number of inlet structures have been designed to distribute the influent flow to a settling basin so that the above-listed factors are satisfied. Giles (1943) presents a thorough historical review of such inlet designs. Those inlet designs which are most inappropriate, and which should not be used in settling basins, are illustrated in Exhibit 3.5.

Screen-type, or orifice-plate, baffles have also been applied to achieve complete flow dispersion over the entire width and depth of settling tanks. Fouling of the screen, however, often prohibits the use of such baffle systems with many waste streams. Envirotech Corp. developed and marketed the Modular Energy Dissipating Feedwell (MEDF), a honeycomb of small tubes mounted across the basin inlet. The honeycomb creates a laminar flow pattern with uniform velocities across the inlet (US EPA 1975). Although effective in distributing the inlet flow, serious plugging of the tubes led to discontinued use of the design.

Submerged weirs, extending across the entire width of a basin, have been found to provide an optimal balance between practicality and flow characteristics for sedimentation. The first submerged weir (Exhibit 3.6) was introduced by Hubbel (1934). Hubbel's design utilizes an upward, diverging flow to the weir crest which greatly reduces flow velocity. The submergence of the weir serves to reduce velocity even further. As well, this weir features a wide, goose-neck crest, which is effective in utilizing any residual approach velocity to distribute the fluid over the vertical depth of the basin. This type of weir is highly effective in distributing the flow over the entire cross-section of the basin with a minimal inlet velocity.

A simplified yet effective version of Hubbel's weir is now commonly used to introduce wastewater streams into sedimentation basins (Exhibit 3.6). Flow enters the settling zone from a header tank at the water level of the settling basin. To smooth the flow, the weir crest, like Hubbell's goose-neck, is typically 30 to 60 centimetres wide and has chamfered edges. The top of the weir should be submerged approximately 15% of the basin depth.

Outlet Design. The discharge of water from settling basins has changed little over the years. Traditionally, an outlet weir extends across the width of the basin at the end opposite the inlet. In circular tanks, the outlet weir extends around the outer periphery; the inlet is at the centre. Clarified effluent overflows into the weir trough and is discharged. The weir rate (volume of water discharged per unit length of weir per unit time) governs the length of the outlet weir. It is critical that the weir edge be level to assure a uniform discharge rate across the entire weir length.

For weirs which are long in relation to the flow (i.e. having a low weir rate), a saw-toothed or V-notch edge is necessary for uniform discharge along the

weir length (Fair and Geyer 1958). Such low-flow systems, however, are virtually non-existent in intensive salmonid culture operations. Conventional municipal wastewater treatment design standards recommend that weir rates not exceed 186 - 248 m^3/d per metre length of weir (ASCE 1959; US EPA 1975). For aquacultural operations, where the solids component of the effluent tends to be heavier and more viscous than conventional municipal wastes, a weir rate of 372 $m^3/d/m$ has been recommended for design purposes (Mudrak 1981).

Caution must be exercised in designing outlet weirs due to the updraft effect generated by such structures, as depicted by the flow net diagram in Exhibit 3.7. As the water approaches the outlet, the horizontal flow velocity increases due to a reduction in cross sectional area and the lifting velocities of stream lines flowing toward the surface weir permit the escape of solids. This is quite evident to the eye at overflow standpipe discharges in tanks, raceways and settling basins. As a result, a certain portion of the tank volume becomes ineffective for settling since suspended particles entering this section become entrained in the effluent flow. The ineffective volume is defined by a concave arc, which extends from a point at the surface of the basin upstream of the weir to a point below the weir, but not necessarily penetrating the full depth of the basin.

Mohlman et al. (1946) developed the following equation to calculate this ineffective volume in a settling basin:

$$\textit{Ineffective Volume} = k \left(\frac{q^2}{V_s^2} \right)$$

where:
- k = constant = 0.134
- q = weir rate ($m^3/d/m$)
- Vs = settling velocity of particles (m/d)

This equation shows that the magnitude of the entrainment effect is proportional to a ratio of the weir rate to settling velocity. Most importantly, however, this is a quadratic equation, meaning that should the weir rate double, the ineffective volume will increase four-fold! Consequently, for every unit increase in the weir rate (q), the corresponding decrease in settling efficiency is disproportionately greater.

Ingersoll et al. (1956), however, contest the value of k, the constant in the above equation, stating that the only proper way to determine the magnitude of entrainment is to characterize the flow net in each specific application. Fortunately, for tanks which are long relative to their width (as is generally the case in aquaculture), the entrainment effect is confined to an upstream distance equivalent to only about 1 to 2 multiples of the basin depth. Since the updraft effect of an outlet weir reduces the effective length of a settling basin, proper design requires that settling basins be lengthened proportionately to compensate for this reduced efficiency. An additional length requirement of 1.5 to 2.0 times tank depth is appropriate in most cases. Weir length should be maximized in all applications.

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3.2.4 Principal Design Considerations

In summary then, for the removal of solids from aquacultural effluents, sedimentation basins should be designed with the following factors in mind:

(1) Overflow rate (Vo), that is, the settling velocity of the smallest particles to be theoretically 100% removed, must be the foundation of basin design.

(2) Detention periods are, of themselves, immaterial; in spite of current industry guidelines which still state retention times (Daley 1989). The detention periods result from the design and are <u>not</u> a basis for design.

(3) Basin depth should be as shallow as possible, providing that scour does not interfere with performance.

(4) Turbulence should be compensated for in basin design equations.

(5) Inlet and outlet structures should be specifically engineered in accordance with the characteristics of the basin dimensions and water flow rates.

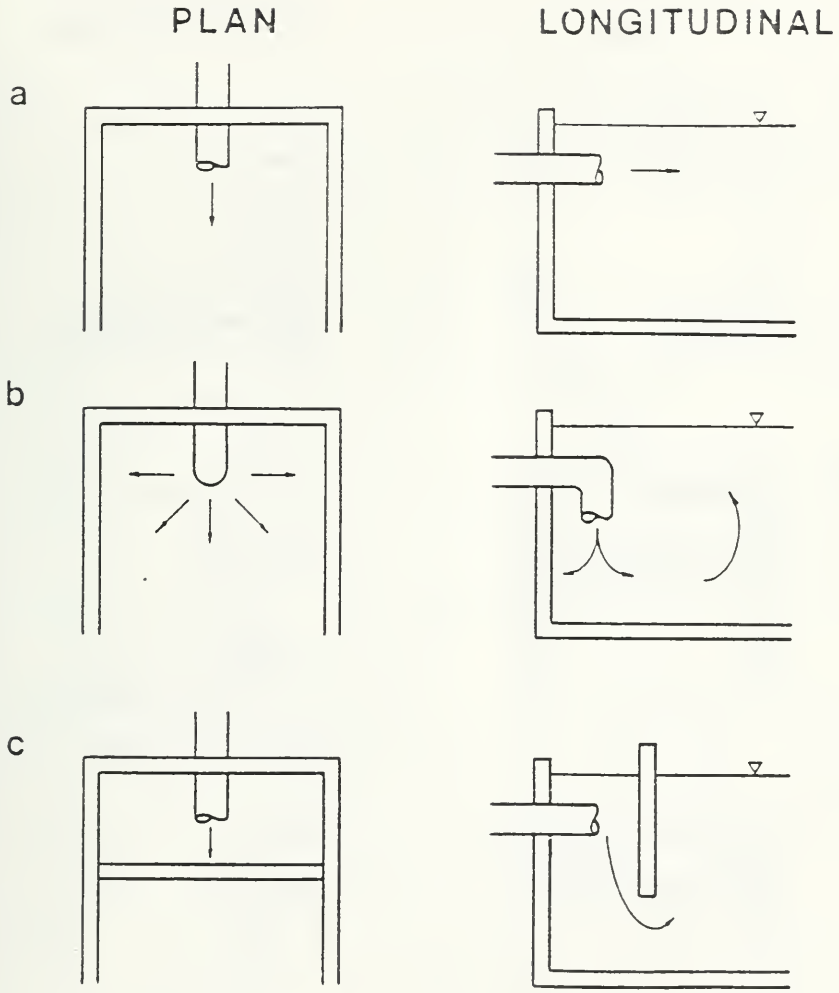

Exhibit 3.5:
Examples of inlet structures which are inappropriate for effective introduction of wastewater into settling basins. a. Straight pipe. b. Downward elbow. c. Straight pipe with target baffle.

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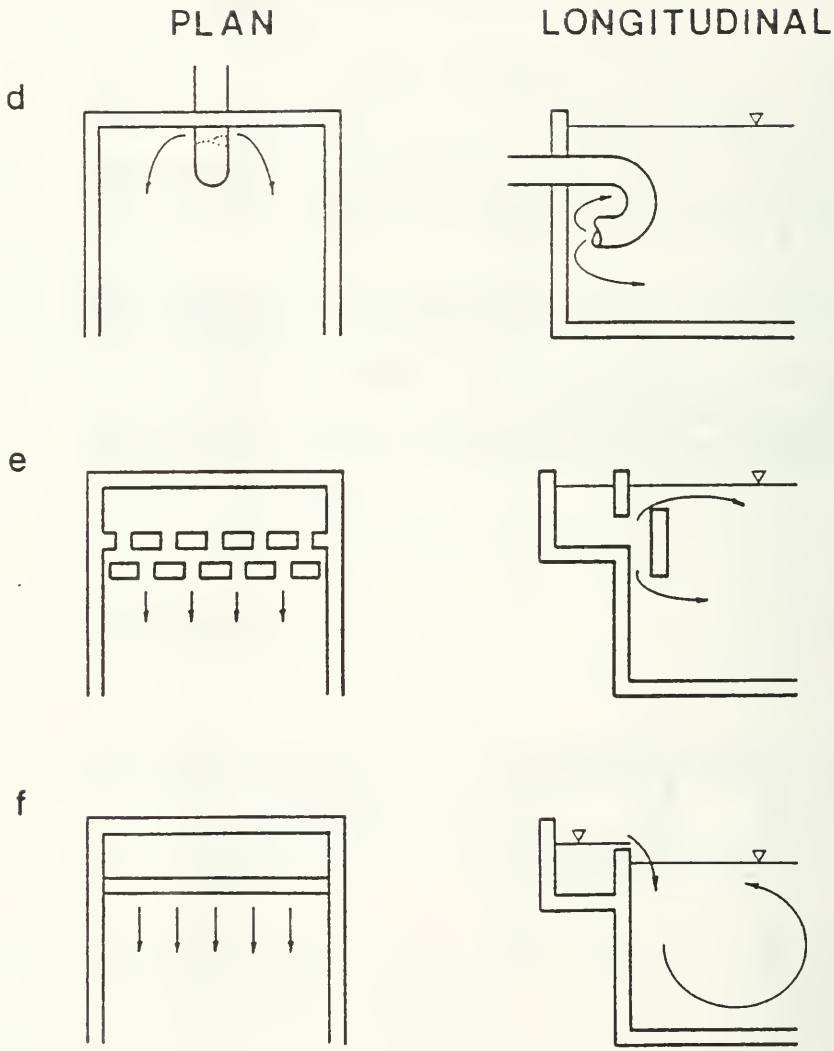

Exhibit 3.5: (cont'd)
Examples of inlet structures which are inappropriate for effective introduction of wastewater into settling basins. d. Reversing-flow. e. Multiple channels with target baffles. f. Free-fall weir.

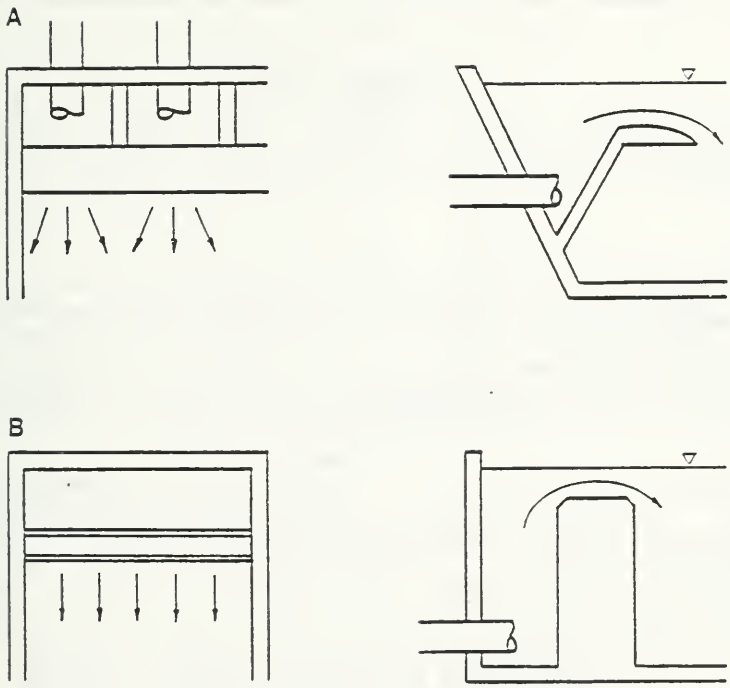

Exhibit 3.6:
Inlet structures designed for effective introduction of wastewater streams into settling basins. A. Hubbel's submerged goose-neck weir. B. Submerged wide-top weir with chamfered edges.

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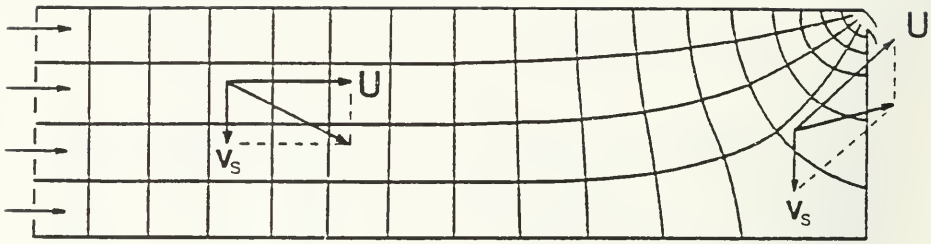
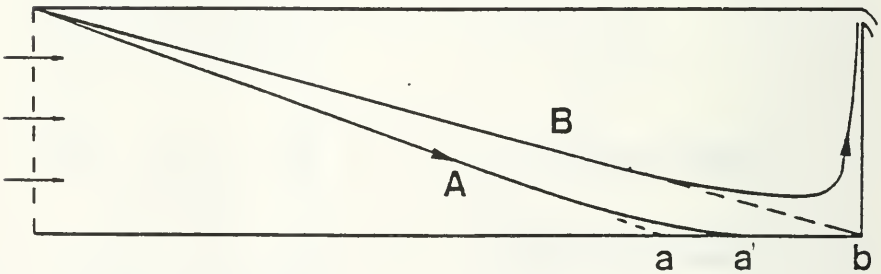


FLOW NET



PARTICLE SETTLING PATHS

Exhibit 3.7:
Two-dimensional representation of outlet weir effects on the fluid flow net and on particle settling paths in a rectangular settling basin. The updraft effect increases the required basin length for settling of particle A from a to a'. Particle B should settle at point b, however, it becomes entrained in the effluent and is discharged.
Source: Adapted from Ingersoll et al. (1956)

4.0 CHARACTERIZATION OF AQUACULTURE OPERATIONS & EFFLUENTS

4.1 Purpose & Objectives

Proper engineering design is essential if aquacultural wastewater treatment facilities are to be effective. Too often, facility design is based upon conventional municipal wastewater treatment design, and the specific characteristics of fish hatchery effluents are not considered. Waste characteristics, however, are the most important factor governing engineering design. Mudrak and Stark (1981) report that the solids component of aquaculture effluents is denser, faster settling, and tends to form a heavier, more viscous sludge than domestic municipal wastes. When these unique characteristics are not considered in facility design, the resultant treatment unit is typically oversized, expensive, and inefficient.

Therefore, settling analyses of the solids component of the wastewater stream must be an integral part of the design process. Surprisingly, however, in the intensive salmonid aquaculture industry, a comprehensive compilation of effluent solids sedimentation data have yet to be compiled and, consequently, the relatively poor performance of effluent treatment operations at such facilities should come as no surprise.

Since a wide variety of particle shapes and sizes exist in most suspensions, calculation of the settling velocity of discrete particles based upon Stokes' Law, or other theoretical equations, is impractical. By conducting a settling analysis of the suspension to be clarified, however, the overall gravitational removal of particles from suspension can be determined for any given overflow rate. The procedure for analysis of suspensions has been somewhat standardized, and is described by several authors (Camp 1946; Fitch 1957; Al-Layla et al. 1980).

Geometric models, although useful in evaluation of hydraulic short-circuiting, cannot be used to measure settling characteristics. Instead, a settling column having an inside diameter greater than 13 cm is required; narrower columns are not reliable due to boundary layer resistance introduced by column walls. To avoid extrapolation of data, the depth of the column should be greater than the depth of a full-scale settling basin in the desired application. Sample ports, where an aliquot of the suspension can be drawn off, are spaced along the side of the column.

Three additional components of fish culture processes must also be assessed in the quest for appropriate aquaculture wastewater treatment systems: (1) analysis of pertinent water quality parameters throughout the culture facility; (2) the design and layout of culture facilities; and (3) standard management practices. The field portion of this investigation was designed to collect these data from commercial, hobby, and provincial fish culture facilities throughout Ontario.

By simultaneously collecting production, facility design, and water quality data, answers to several key questions can be obtained:

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Q. WHAT is the impact of intensive fish culture operations on water quality?

Q. WHICH production and facility design factors contribute to the deterioration of water quality?

Q. HOW do the suspended solids behave under quiescent settling conditions?

Q. WHAT are the values of critical design components at existing effluent treatment facilities on fish farms and how are they related to the operating efficiency of these facilities?

Several previous studies have addressed the first question, however, it is the inter-relationship of answers to all four questions that makes this investigation unique and, furthermore, that will provide practical solutions for effluent management at fish culture facilities. Such answers will identify those variables which facilitate the segmentation of fish culture operations into discernible groups, based upon similarities in design and operating characteristics of the production unit. Past research has already shown that different farms can have substantial differences in solid and dissolved waste output (Ont. Min. of Environment 1982; Hilton and Slinger 1984; Merican and Phillips 1985). The compilation of a broad data base will enable the design of effective effluent treatment facilities based upon the characteristic traits of a given farm and the associated production features of the group to which that farm belongs.

Protection of the receiving water course must be a prime consideration in the design, construction, and operation of any aquaculture facility. Standardization of design criteria for the various types of culture facilities, and the development of proper management practices, will enhance the responsible use of aquatic resources by aquaculturists. Moreover, standardization of design principles will provide confidence to decision-makers in their evaluation of aquacultural wastewater treatment facilities, thereby permitting the identification of the underlying cause(s) of non-compliance; i.e. whether the problem hinges on a design factor or poor management practices.

4.2 Field Survey & Water Quality Sampling

A field monitoring program was developed during the summer of 1989 through the cooperative efforts of The Ontario Trout Farmers' Association (OTFA), the Ontario Ministry of the Environment (OME), the National Research Council of Canada (NRC), and the Faculty of Engineering Science at The University of Western Ontario (UWO). The survey goal was to schedule site visits to approximately 60 to 90 commercial, community, government, and private fish farms across Ontario. For practicality, Southern Ontario was the principal study area. Moreover, this region has the largest concentration of fish farms in the province. Over the course of the field season, site visits were scheduled to fish farms which were progressively further from the operating base in London, Ontario.

A summer student from the Faculty of Engineering Science at UWO was hired and trained to conduct the field portion of this investigation, which included:

- contacting fish farm operators and scheduling site visits;
- collecting production and operations data from respondent farm managers;
- conducting on-site sedimentation tests at fish culture facilities;
- collecting representative water chemistry samples and delivering samples to the OME laboratory for nutrient analyses;
- conducting suspended solids filtration analyses in the engineering laboratories at UWO; and
- maintaining project records.

Data collection was organized into three principal categories:

A. PREDICTOR VARIABLES
   (1) Production and Management Variables

B. RESPONSE VARIABLES
   (2) Water Chemistry Variables
   (3) Solids Settling Variables

Predictor variables consist of those production and management practices, and specific facilities design features, which characterize the fish culture operation. These data were collected to illuminate potentially causative agent(s) of deteriorating water quality. Response variables are those parameters of primary concern from a water quality and effluent management perspective. A standard data sheet was compiled to facilitate the collection of similar data from all operations included in the study (see Appendix I).

4.2.1 Predictor Variables

Predictor variables were divided into three groups to facilitate data management.

Operations data provide information on the size of the operation in terms of annual production capacity, the brand and type of feed used, and the source and total volume of water used.

Since many fish culture operations utilize different culture units (i.e. circular tanks, raceways, troughs, ponds, etc.), an on-site decision was made by the investigator to conduct detailed sampling within a particular culture unit. Sampled Unit data provide information on the type and dimensions of the culture unit sampled, the total weight (or number) and size of fish in the unit, the method of feeding the fish (i.e. hand, demand feeder, automatic feeder) and the temperature and volumetric flow of water to the unit. As well, if water re-use was being utilized, the percentage of the total flow which was comprised of re-used water was also recorded.

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According to the findings of UMA Engineering Ltd. (1988), 26% of all fish culture operations in the province utilize some form of effluent treatment. At those operations where treatment facilities were in operation at the time of the site visit, data were collected to permit an evaluation of the design parameters and operating efficiency of the treatment unit. Effluent Treatment data provide information on the treatment technology in place, the dimensions of the treatment unit, the hydraulic loading rate of the unit, and the design of inlet and outlet structures.

For most farms, sketches of the overall farm layout and process water flow paths were compiled to assist with data compilation and interpretation.

4.2.2 Response Variables

Response variables are divided into two distinct groups: water chemistry variables and solids settling variables.

At each fish culture operation, Water Chemistry Variables were collected in standard 1 litre sample bottles. The location and number of these samples varied somewhat with the nature of the culture facility; however, the influent source water and the final farm discharge were sampled at all operations. Samples were collected at the end of the "sampled production unit" and prior to and following effluent treatment, if the latter facilities were in operation.

The water quality parameters that were analyzed included total Kjeldahl nitrogen (TKN), total ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), total phosphorus (TP), dissolved phosphorus (DP), and total suspended solids (TSS). These parameters were targeted as being of most concern at a meeting of OME and OTFA representatives during the early planning phases of the investigation. Except for TSS, all water quality analyses were conducted by the OME at their analytical laboratory in London, Ontario. To ensure the confidentiality of individual fish culture operations included in the study, all samples were identified by a "Farm Number" only. Moreover, only the principal researchers have a record of the farm numbers and farm names.

To facilitate the segmentation of farms into discernible groups, and to enable the definition of principal effluent treatment design criteria, Solids Settling Data were also collected. A settling column measuring 220 cm high by 20.4 cm inside diameter was used to conduct on-site settling tests. Three sampling ports, located at distances of 120, 160, and 200 cm from the top of the column, were used to draw off samples for solids content analysis. Based upon past experience, two shallower ports (40 and 80 cm) were not used during this investigation.

Settling tests were conducted by filling the column to capacity with approximately 45 litres of water from the production/treatment unit. At most facilities, it was necessary to re-suspend solids within the unit to gather samples having a sufficient concentration of solids for the analysis. Once in the column, the suspension was gently agitated by introducing compressed air through a sparger at the bottom of the column. Agitation serves to create a

gentle rolling action in the column, thereby creating a uniformly mixed suspension from which to draw initial samples from each sampling port.

Following collection of the initial samples, the air supply was discontinued and the column contents were permitted to settle under quiescent conditions. Samples were collected at timed intervals, which spanned a one-hour period. Past experience by the principal investigator has indicated that longer time periods (up to three hours) do not improve the results. All samples were vacuum filtered through Type 11306 Sartorius Membrane Filters, having a pore size of 0.45 μm, to determine the total suspended solids concentration.

The sedimentation analyses provide information pertaining to the shape of the cumulative solids settling curve, which was discussed in Section 3.1. The slope and intercept of the curve(s) provide information pertaining to the value of Cr at various design overflow rates (settling velocities), and are thus vital to the design of treatment facilities.

Settling data were not collected at all farms. Pond operations were largely excluded from this portion of the investigation due to the complexities introduced by suspended organic and inorganic matter naturally present in ponds. Additionally, settling tests were not conducted at farms where solids removal (via vacuuming, flushing, etc.) had not been conducted within the past seven days. Parjala (1984) suggests that solids be less than one week old to obtain reliable results. Generally, most operators had cleaned solids from their facilities within the four days prior to the site visit.

4.2.3 Scope and Limitations

This field investigation was designed to enable the collection of data from a number of fish culture operations to provide a sufficiently broad data base to permit the segmentation of operations into discernible groups based upon production and management characteristics. Moreover, it was designed to maximize the co-operative efforts of all parties involved. To conduct a survey of this magnitude, over a geographic region the size of Ontario, necessitates that the time spent at individual sites be utilized efficiently.

Although composite sampling and/or multiple sampling programs offer certain advantages, the time required for such activities would greatly limit the total number of operations which could be visited, given the size of the geographic region surveyed in this study. Instead, grab samples were collected at each farm. Similarly, the utilization of filtered effluent samples and/or re-suspended solids for settling tests also permitted a larger number of sites to be visited during the sampling period. Nevertheless, additional insight may be provided through collection of solids in sediment traps for a 1 to 4 day period prior to conducting the sedimentation test. To dispel any argument regarding the solids sampling procedures applied in the field study, statistical comparison of settling data from re-suspended and filtered samples revealed no difference in settling behaviour. Similarly, no such differences were identified by CAS in studies conducted in New Brunswick.

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Despite these limitations, the study did achieve its objective of obtaining data from a number of fish culture operations; a data set which may, in fact, be unparalleled in the industry. Additionally, the nature of the data collected at all operations is essentially identical, thereby, incorporating uniformity into the investigation and subsequent interpretation of the results.

4.3 Data Analysis & Results

Between May 14 and September 2, 1989, a total of 82 fish culture operations were visited throughout Southern Ontario. From this sample, full data sets, including settling data, water chemistry data, and production and management data, were obtained from 50 farms. Partial data sets were obtained from the remaining 32 farms. The latter are predominantly pond culture operations and, therefore, settling data were not collected. The following presentation of data analyses and results is largely based upon those 50 farms with complete data sets. Data from all farms visited are presented in Appendix II.

In total, 25 continuous variables (12 predictor variables; 6 solids settling variables; and 7 water chemistry variables) and 4 class, or non-continuous, variables (farm type; feed brand; feed type; and feeding method) were recorded. These variables are defined in Exhibit 4.1.

Prior to data analyses, all continuous data were transformed to natural logarithms to conform with assumptions of the various statistical methods. For each observation (z) the transformation equation is as follows:

$$\text{transformed value of } z = \ln((z+1) - \text{minimum } z \text{ value})$$

By subtracting the minimum observed value from each variable, the data are adjusted for differences in measurement scales and units; adding 1 eliminates the potential for negative values associated with the logarithmic transformation of numbers less than 1.0.

Since one of the underlying goals of this investigation is to reveal cause-and-effect relationships between fish culture practices and deterioration of water quality, Pearson's (parametric) and Spearman's (non-parametric) correlation analyses were conducted on the entire data set to examine the nature of the relationships between variables. Key relationships between predictor variables and response variables were scrutinized. As suspected, however, very few statistically significant relationships were revealed using this statistical approach, suggesting that considerable variability exists among intensive salmonid culture operations. As a result, data for the various farms were examined to determine whether different types of farming operations were evident.

Due to the physical layout and construction of intensive fish culture operations in Ontario, it is relatively simple to separate farms on an *a priori* basis. That is, flow-through raceway facilities are distinct from oval raceways, and similarly from flow-through circular tanks, ponds, and intensive recirculation units. Consequently, data were re-organized into the following five groups prior to subsequent analyses.

Group 1 — Standard raceway operations in which water enters at one end, flows through the length of the unit, and is discharged at the opposite end.

Group 2 — Oval raceway operations resembling modified Burrows ponds in which two parallel raceways share a common dividing wall, which stops short of either end of the unit. Water circulates around the unit such that the flow on each side of the central wall is in opposite directions. High-volume low-head pumps are commonly used to maintain circulation within the tank. Overflow drains are usually located at one or both ends.

Group 3 — Circular tank operations consisting of concrete, steel, or fiberglass tanks having a circular flow of water from the outer edge toward a central drain.

Group 4 — Pond culture operations in which fish are raised in earthen excavations, generally square to rectangular in shape and having a water inlet and outlet at opposite reaches of the pond.

Group 5 — In all groupings, it is usually difficult to categorize certain individuals. Rather than attempting to force decisions which may compromise results, Group 5 was created to include any farms which did not fit into Groups 1 through 4. (Others)

Using this *a priori* approach, the 50 farms were re-classified as follows:

Group	(n)
1	21
2	11
3	12
4	3
5	3

Having re-classified the data into separate types of facilities based on configuration, it was necessary to determine whether this classification strategy was statistically meaningful, based upon the observed variables. Using multivariate analysis of variance (MANOVA), the five groups were, in fact, found to be significantly different.

Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Num DF	Den DF	Prob.
Wilks' Lambda	0.007388	2.1007	100	85.6	0.0003

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From a univariate perspective using standard analysis of variance (ANOVA), significant differences between groups were identified in both production variables and water chemistry variables; no differences were found in the solids settling data. Differences in intensity, production area, standing crop, density, water flow, water reuse, and hydraulic retention time are responsible for distinguishing at least one of the five groups. Similarly, groups were found to differ with respect to all seven water chemistry variables (i.e. pre-treated effluent quality).

To confirm this finding, and to visually present the magnitude of the difference between the five groups, a canonical discriminant analysis (CDA) was completed. CDA uses linear combinations of the observed variables in a multivariate approach to construct composite variables, which are comprised of components of all 25 observed variables. Canonical variables, or "axes," serve as the basis for classifying farms into one of the groups to confirm group membership and thereby identify unusual individual farms that fail to fit into the *a priori* grouping. One canonical axis is developed to maximally separate each pair of groups based upon the degree of variation inherent in the original data (for 5 groups, 4 canonical axes are generated). The analysis identifies variables which separate groups in combination as opposed to separating them on a "one variable at a time" basis (Campbell and Atchley 1981).

The CDA did indeed support the finding of the MANOVA, indicating that significant differences ($P<0.025$) exist between the groups. The CDA results (Exhibit 4.2) illustrate that differences are significant along the first two canonical axes, which account for 79.6% of the variance between groups. The third and fourth axes, which account for the remaining 20.4% of the total variance, were not significant ($P>0.320$).

The five groups are plotted on the resultant canonical axes 1 and 2 to visually display the five groups on X-Y co-ordinates (Exhibit 4.3). This graph illustrates that considerable overlap exists between Groups 1 and 3, standard raceways and circular tanks. The degree of overlap appears to be greater along axis 2 than on axis 1. Oval raceways (Group 2) are significantly removed from Groups 1 and 3 along axis 2, and from Group 3 (circular tanks) along axis 1. Groups 4 and 5 (ponds and "others") are separated from all other Groups, and each other, along axis 1. The implications of this pattern is revealed by examining the canonical coefficients presented in Exhibit 4.4.

Standardized Canonical Coefficients are used to derive the actual data points which are plotted in Exhibit 4.3; they are the raw canonical coefficients, standardized to a standard deviation equal to unity. The total, within, and pooled canonical structures, however, reveal the correlations between the original data and the canonical axes. More importantly, each structure presents a different aspect of the inter-relationship between and within groups.

The total canonical structure assumes that no groups exist. Generally, this summary reveals few strong correlations, however, significant correlations are indicative of important variables across all five groups. This analysis suggests that along canonical axis 1, the axis which maximally separates Groups 5 (others), 3 (circular tanks), and 2 (oval raceways), segmentation is principally due to differences in intensity of production, total water flow,

water reuse, hydraulic retention time, and nitrate concentration. Along axis 2, which separates oval raceways from all other groups, principal segmentation variables include production area, standing crop biomass, total water use, and water reuse from a production perspective. Moreover, from a water chemistry perspective, axis 2 reveals differences with respect to ammonia, total Kjeldahl nitrogen, nitrite, total phosphorus, and dissolved phosphorus (Exhibit 4.4).

The between canonical structure compares the five groups collectively, using the mean. or centroid, of each group as the basis for comparison rather than the individual observations within each group (i.e. n=5 versus n=50). This approach identifies those variables which act to distinguish groups and is similar to MANOVA in that multi-variable interaction is used to reveal differences. The high correlation coefficients for the between canonical structure along both axes in Exhibit 4.4 suggest that nearly all of the measured variables contribute to group segmentation. In fact, density is the only variable which is not highly correlated on either canonical axis, suggesting that the between-group differences are not attributed to this variable.

Lastly, the within canonical structure questions the degree of variability for each variable within each group and across groups. That is, it considers whether the role of one variable in one group is similar to the relationship of that same variable in other groups. High correlations suggest that a relationship exists within groups and across groups. The data in Exhibit 4.4 show no strong correlations along axis 1; however, area, total water flow, water reuse, ammonia, total Kjeldahl nitrogen, total phosphorus, and dissolved phosphorus are correlated along axis 2. For these variables, the correlation that exists within each group is similar to the correlation that exists between groups.

Groups 4 and 5, that is pond production and "other" facilities, are of limited significance to the objective of this investigation. The use of ponds continues to decline in the industry due to their inherent inefficiency from management, harvesting, and product quality perspectives. Moreover, this group is largely unrepresented in the data since settling tests were not conducted at most facilities. "Other" facilities are also of little meaning since, from a categorical viewpoint, these farms are essentially misfits. Each of these three operations did not readily fit into one of the other four groups, and each was placed into Group 5 for different reasons. As such, there are no representative characteristics of Group 5 farms in contrast to the farms in other groups.

Consequently, Groups 4 and 5 were removed from the data set for subsequent analyses. The small size and overall irrelevance of these groups only introduces unnecessary variability into the analyses which can potentially misdirect the interpretation of results.

Again, significant differences between Groups 1, 2, and 3 were confirmed by MANOVA and ANOVA. Furthermore, the impact of standard raceways, oval raceways, and circular tank production facilities are more pertinent to the investigation.

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Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Num DF	Den DF	Prob.
Wilks' Lambda	0.047601	2.4367	50	34	0.0037

ANOVA results, including Student-Newman-Keuls multiple range testing, are presented in Exhibit 4.5. Among the predictor variables, significant differences ($P<0.007$) between groups are associated with production area, standing crop, water flow, water reuse, and hydraulic retention time. With respect to production area and water reuse, the mean values for oval raceway operations are significantly greater from both standard raceway and circular tank operations ($P<0.0010$). The latter two groups are not different with respect to these variables. Hydraulic retention time was found to be significantly greater in both oval raceways and circular tanks than in standard raceway operations ($P=0.0064$). The total volumetric water supply to each of these three groups was found to be different ($P=0.0001$; oval raceways > standard raceways > circular tanks).

Five of the seven water chemistry variables were found to differ significantly between the 3 groups (Exhibit 4.5). Only the concentration of nitrate and total suspended solids produced in fish culture facilities did not differ ($P>0.4197$). Interestingly, however, for the other five variables (i.e. TKN, NH_3, NO_2, TP and DP) oval raceway operations were found to be different from both standard raceways and circular tanks ($P<0.0295$). In all cases, the concentration of these five nutrients is greatest in oval raceways. Although the mean values for circular tank operations are consistently larger than the mean values for standard raceways, these differences are not significantly different ($P>0.05$).

Canonical discriminant analysis was used to further define the relationship between these three groups and, again, the CDA results confirm those of the MANOVA and ANOVA analyses. Since three groups are being compared, two canonical axes are generated. Only axis 1 is significant ($P=0.0037$), accounting for 76.8% of the variability between the 3 groups (Exhibit 4.6).

These CDA results are graphically presented in Exhibit 4.7. It is apparent that considerable overlap remains between Groups 1 and 3 (standard raceways and circular tanks) along axis 2, the axis which presents no significant difference ($P=0.2250$). Along axis 1, however, it is evident that Group 2, oval raceways, is significantly different from Groups 1 and 3.

Examination of the total, between, and pooled within canonical structures for this analysis lends insight into the source of these differences (Exhibit 4.8). The total canonical structure indicates that strong correlations exist across several variables, including the port slopes, production area, standing crop, total water flow, water reuse, and five of the seven water chemistry variables, suggesting that these variables contribute strongly to group segmentation. The between canonical structure suggests that group differences are not related to fish density. Additionally, however, the concentration of total suspended solids produced during fish production is also eliminated as a

source of group difference. Lastly, the pooled within structure re-confirms that total water use, water reuse, and nitrate production display patterns within each group which are similar (Exhibit 4.8).

Having identified that the fundamental design of fish production facilities is indeed a basis for separating the groups, we then examined individual groups to further quantify and qualify the impact of fish production practices and system design on the quality and treatment of discharged effluent. Correlation analysis is a tool for revealing relationships between the observed variables. Both Pearson's (parametric) and Spearman's (non-parametric) correlation analyses were used to resolve patterns in the transformed data sets for Groups 1, 2, and 3 individually.

Differences between Pearson's and Spearman's analyses revealed that some of the relationships were not linear. Consequently, Spearman's correlation analysis was considered to be more appropriate. This technique compares data on a rank order basis and provides a more conservative interpretation of results. Tables of Spearman correlation coefficients and the corresponding statistical probabilities are attached in Appendix III.

A number of the predictor variables (i.e. production area, depth, flow, density, etc.) were highly correlated; this was to be expected since many of these variables are inter-related by design. For example, the carrying capacity of an operation (standing crop) is generally related to the available supply of water. Similarly, the solids settling data and water chemistry data tend to be highly correlated with their own kinds. More importantly, however, we must understand the relationships between the predictor variables and both solids settling variables and water chemistry variables to properly assess the impact of aquaculture operations on water quality, and thereby facilitate the design of effective effluent treatment units.

With respect to solids settling data, few statistically significant correlations exist in any of the three groups (Appendix III). Furthermore, among those relationships that are significant, little meaning can be inferred because the correlated variables have little relevance from a design or management perspective. This suggests that, individually, none of the predictor variables are correlated with solids settling behaviour.

In comparison, however, a number of meaningful relationships have been identified between production and water chemistry variables. In standard raceways, oval raceways, and circular tanks, increases in intensity and fresh water intensity are significantly correlated ($P<0.097$) with an increase in the concentrations of TKN, TP, and/or DP in the effluent (Exhibit 4.9). In circular tanks, these same two production variables are also positively correlated with the effluent concentration of NH_3. The depth of production facilities and the weight of the standing crop of fish are correlated with the concentration of TKN in effluent waters in standard raceways and circular tanks. Increases in crop and density are highly correlated ($P<0.048$) with increases in effluent TP in circular tanks as well. Weak positive correlations ($P<0.099$) exist between average fish size and TKN and NO_2 in standard raceways and circular tanks. There is also evidence suggesting a positive correlation between average fish size and TP concentration in circular tanks.

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Once again, similarities between standard raceways and circular tanks, and dissimilarities between these two groups and oval raceways, are revealed (Exhibit 4.9). Depth and average fish size correlate with on water quality in both standard raceways and circular tanks, yet they do not correlate in oval raceway operations. Additionally, total flow and water reuse are not correlated in standard raceways and circular tanks, but they display positive correlations in oval raceways. The production variables for which no meaningful correlations were identified across all three groups include hydraulic retention time, annual production, area, and temperature. Conversely, intensity and fresh water intensity are most highly correlated across all groups.

The objectives of this investigation clearly suggest a need for the establishment of design criteria to facilitate solids removal from fish culture process water. The data analyses, however, have not yet characterized solids settling patterns. As discussed in Section 3.1, settling data can be plotted to yield a cumulative distribution curve, which is a principal tool in the design of sedimentation basins. Such data were collected at 50 farms during the field sampling portion of this study. The data from the 44 operations comprising Groups 1, 2, and 3 have been analyzed using regression analysis, and compared using an analysis of covariance (ANCOVA).

When all of the transformed settling curve data from each farm are pooled within the three respective groups, significant regressions are obtained ($P<0.001$). The un-transformed regression lines (settling curves) for standard raceways, oval raceways, and circular tanks are plotted in Exhibit 4.10. The data obtained at each farm from the three sampling ports on the settling column fit a single regression line, with an overall average coefficient of determination (r^2) greater than 63.8%. This confirms that settling is indeed discrete in intensive salmonid fish culture. The regression equations for the pooled data set for each group are presented below:

Group	Equation	t	P	n	r^2
Std. Raceways	$\ln Cr = 0.09889 + 0.80730 \ln Vo$	21.77	$P<0.001$	270	0.638
Oval Raceways	$\ln Cr = 0.31979 + 0.72947 \ln Vo$	16.80	$P<0.001$	159	0.640
Circular Tanks	$\ln Cr = 0.06397 + 0.72781 \ln Vo$	16.65	$P<0.001$	151	0.648

ANCOVA was used to identify similarities and differences between these three regressions. An F_{max} test confirmed homogeneity of variance prior to conducting the ANCOVA. The analysis indicates that the slopes of all three lines are not significantly different ($F=0.6485$; $P>0.05$); however, the intercepts are different ($F=5.5180$; $P<0.01$). Interestingly, it is the intercept of the cumulative distribution curve for oval raceways which is significantly different from the intercepts of standard raceways and circular tanks. The latter two are not significantly different, thereby further emphasizing the similarities between these two groups.

ANCOVA's were also used to compare farms within each group and to determine the degree of within-group variation. For all three groups, clusters of farms were found to have regression equations which were different from other subsets within the group. The number of clusters, and the degree of overlap between clusters, indicates that these within-group differences are subtle, and are likely relatively unimportant in comparison with the between-group differences. Feed brand, feed type, and feeding method were also explored as possible sources of between group differences but no pattern was evident.

The class variable "feed brand" was also examined as a possible contributor to differences in effluent water quality. Effluent water chemistry data were regrouped by the brand of feed used at the culture facility. The groups consisted of (1) users of Martins Feed[1]; (2) users of Zeigler's Feed[2]; and (3) users of a combination of these two brands. No other feed brands were identified in the survey.

MANOVA was used to assess the impact of feed brand on effluent water quality. No significant difference was found between groups.

Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Num DF	Den DF	Prob.
Wilks' Lambda	0.82044	0.60926	14	82	0.8500

Furthermore, univariate F-tests (ANOVA) revealed no significant difference ($P>0.406$) in effluent concentrations of ammonia, TKN, nitrite, nitrate, total phosphorus, dissolved phosphorus, or total suspended solids between farms using either feed brand.

Similarly, MANOVA and ANOVA were used to determine the effect of feed brand on solids settling characteristics. As before, no significant differences were observed using either univariate or multivariate techniques ($P>0.232$).

Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Num DF	Den DF	Prob.
Wilks' Lambda	0.86624	0.79783	6	31	0.5790

As a result, there is no evidence of differences in effluent water quality or solids settling characteristics associated with feed brand.

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[1] Martin Feed Mills Ltd., Elmira, Ontario.

[2] Zeigler Bros., Inc., Gardners, PA.

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4.4 Chapter Summary and Principal Findings

4.4.1 The five *a priori* groups of farms (i.e. standard raceways, oval raceways, circular tanks, ponds, and others) display significant differences with respect to design, operating, and untreated effluent water quality perspectives. Most notably, while standard raceways and circular tanks appear to be similar across several production and operational aspects, oval raceways differ significantly from these other two groups. Oval raceways have larger production areas, and they re-use substantially more water. Moreover, the quality of untreated effluent from oval raceways has higher concentrations of TKN, ammonia, nitrite, total phosphorus, and dissolved phosphorus than do the other two facility designs. Again, standard raceways and circular tanks were found to be statistically similar. No differences were found with respect to effluent suspended solids and nitrate concentrations across all three groups. Water use did differ significantly across all groups, however, with the greatest amount of water being used by oval raceways, followed by standard raceways, and circular tanks.

4.2.2 Strong correlations exist between production parameters and untreated effluent water quality. Most notably, increased intensity (i.e. carrying capacity) and fresh water intensity are related to increased concentrations of dissolved nutrients (TKN, TP, and/or DP) in all three groups of production facilities. Fish density is not correlated with any of the water quality variables in standard raceways, however, increased density is significantly correlated with ammonia concentrations in oval raceways and with total phosphorus concentrations in circular tanks. Average fish size and production depth were also related to water quality (NO_2, TKN, TP, DP) in standard raceways and circular tanks, but not in oval raceways. This further substantiates the similarity between standard raceways and circular tanks and the differences between these two groups and oval raceways. Since water re-use is principally practiced only in oval raceways, it is understandable that only this group displays correlations between water re-use and effluent water quality.

4.3.3 The retention time of water in the production facility, total production area, total water use, and annual production capacity of a farm are not related to any aspect of effluent water quality. This suggests that all farms, big and small, have the potential to pollute receiving bodies of water. Temperature is not correlated with effluent water quality in all three groups.

4.4.4 Solids settling behaviour differs moderately within individual groups, however, the between-group differences are highly significant and inherently more meaningful. While the production effluent from standard raceways and circular tanks displays statistically similar solids settling curves, the curve for oval raceways is shifted to the left. This indicates that the suspended solids fraction in oval raceway production effluents settles significantly slower than that in the other production systems.

Exhibit 4.1:
Definition and units of measure for the 25 continuous and 4 class variables observed and recorded at the time of the site visit. The abbreviated name used in the results section is also presented.

Variable Name	Units	Abbr.	Definition
Predictor Variables - Continuous			
Intensity	(kg/Lps)	INTEN	The approx. biomass of fish within the observed production unit per unit water flow.
Annual Production	(kg)	PROD	The approx. total weight of fish produced at the facility each year.
Production Area	(m^2)	AREA	The surface area of the sampled production unit.
Production Depth	(m)	DEPTH	Average depth of the sampled production unit.
Standing Crop	(kg)	CROP	The approx. weight of fish within the sampled production unit.
Density	(kg/m^3)	DENS	The approx. weight of fish per unit volume in sampled production unit.
Water Flow	(Lps)	FLOW	Total water flow through sampled production unit.
Water Reuse	(%)	REUSE	The percentage of total flow (Q) reused within the production unit.
Fresh Water Intensity	(kg/Lps)	FWI	The approx. weight of fish within the sampled production unit per unit volume source water added.
Temperature	(°C)	TEMP	Water temperature.
Average Fish Size	(g)	SIZE	The average weight of an individual fish within the sampled unit.
Hydraulic Retention Time	(min)	HRT	The theoretical retention time of water within the production unit based on volumetric flow of source water.

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Exhibit 4.1: (cont'd)
Definition and units of measure for the 25 continuous and 4 class variables observed and recorded at the time of the site visit. The abbreviated name used in the results section is also presented.

Variable Name	Units	Abbr.	Definition
Predictor Variables - Class			
Farm Type	--	GROUP	Standard raceways, oval raceways, circular tanks, ponds, other.
Feed Brand	--	FEED	Martins, Zeigler's, combination of Martins & Zeigler's, other.
Feed Type	--	TYPE	Sinking, floating, combination.
Feeding Method	--	METH	Hand, demand, automatic, other.
Response Variables - Settling Data			
Slope - Port 1	--	m1	Slope of regression line for [TSS] versus time for 120 cm port samples.
Slope - Port 2	--	m2	Slope of regression line for [TSS] versus time for 160 cm port samples.
Slope - Port 3	--	m3	Slope of regression line for [TSS] versus time for 200 cm port samples.
Slope - CDC	--	mCDC	Slope of regression line for the cumulative distribution curve for sedimentation data.
Intercept - CDC	--	INTPT	Intercept of regression line for the cumulative distribution curve for sedimentation data.
Coefficient of Determination - CDC	--	r^2	Coefficient of determination of the regression equation for the cumulative distribution curve for sedimentation data.

Exhibit 4.1: (cont'd)
Definition and units of measure for the 25 continuous and 4 class variables observed and recorded at the time of the site visit. The abbreviated name used in the results section is also presented.

Variable Name	Units	Abbr.	Definition
Response Variables - Water Chemistry			
Total Kjeldahl Nitrogen	(mg/L)	TKN	KSO_4 / H_2SO_4 Digestion - Colorimetric @ 630 nm
Total Ammonia	(mg/L)	NH_3	Undigested - Colorimetric @ 630 nm
Nitrite	(mg/L)	NO_2	Undigested - Colorimetric @ 520 nm
Nitrate	(mg/L)	NO3	Undigested - Colorimetric @ 520 nm
Total Phosphorus	(mg/L)	TP	KSO_4 / H_2SO_4 Digestion - Colorimetric @ 880 nm
Dissolved Phosph.	(mg/L)	DP	Undigested - Colorimetric @ 880 nm
Total Suspended Solids	(mg/L)	TSS	Filtration through 0.45 µm membrane filter paper.

Exhibit 4.2:
Canonical discriminant analysis - statistical results for segmentation of five *a priori* groups of salmonid fish culture facilities.

CANONICAL AXIS	CANONICAL CORRELATION	EIGENVALUE	PROPORTION	CUMULATIVE PROPORTION
1	0.921	5.629	0.495	0.495
2	0.880	3.423	0.301	0.796
3	0.761	1.376	0.121	0.917
4	0.697	0.943	0.083	1.000

CANONICAL AXIS	LIKELIHOOD RATIO	APPROXIMATE F VALUE	NUM D.F.	DEN D.F.	PROBABILITY
1	0.007	2.101	100	85.8	0.0003*
2	0.049	1.613	72	66.6	0.0248*
3	0.217	1.149	46	46.0	0.3204
4	0.515	1.029	22	24.0	0.4707

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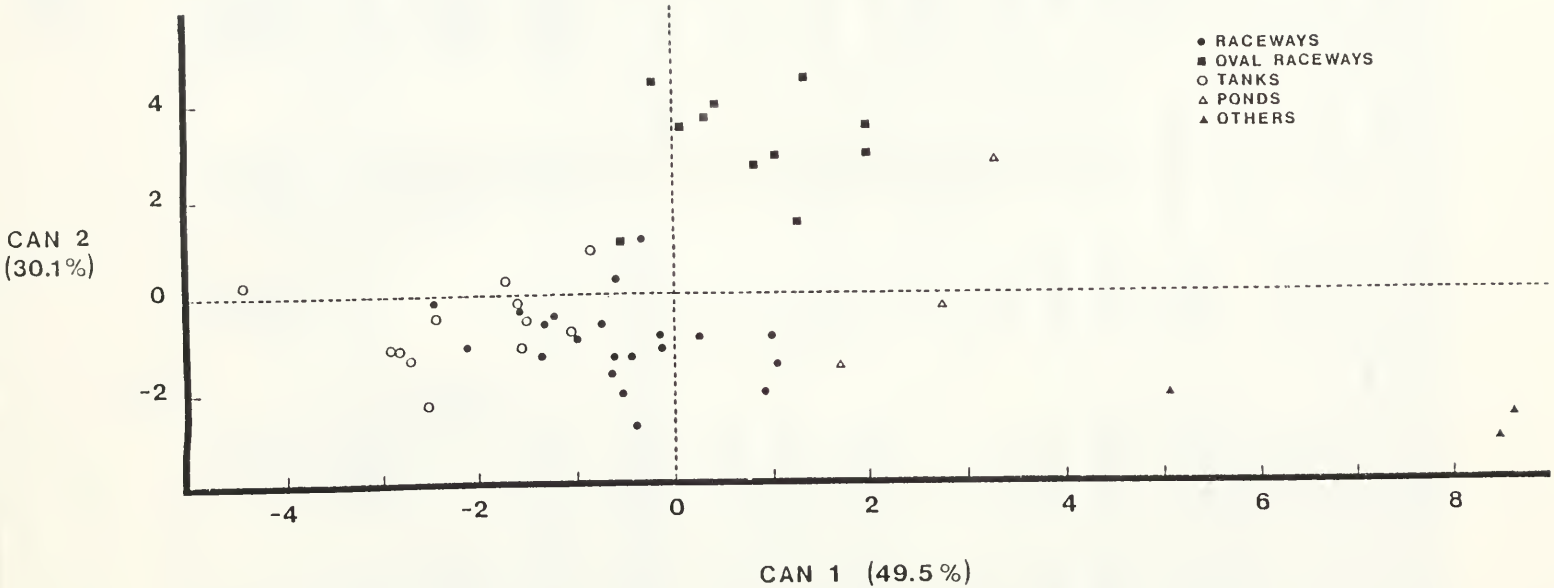

Exhibit 4.3:
Canonical discriminant analysis: Plot of canonical axes 1 and 2, identifying group segmentation among five classes of commercial trout culture facilities. Both axes are statistically significant ($P<0.025$). Bracketed value indicates percentage of observed variance accounted for in axis.

Exhibit 4.4:
Canonical Discriminant Analysis: Canonical coefficients and total, within and between canonical structures for Groups 1 - 5. Correlation coefficients >0.30 are meaningful.

Variable	Standardized Coefficients		Total Canonical Structure		Between Canon. Structure		Pooled Within Structure	
	CAN1	CAN2	CAN1	CAN2	CAN1	CAN2	CAN1	CAN2
m1	0.164	-0.369	0.102	0.251	0.381	0.894	0.041	0.123
m2	-0.088	0.219	0.219	0.221	0.699	0.672	0.089	0.110
m3	0.112	-0.097	0.077	0.291	0.256	0.923	0.031	0.144
SLOPE CDC	-0.611	-0.118	-0.057	-0.145	-0.202	-0.491	-0.023	-0.071
INTERCEPT CDC	-0.055	0.199	0.113	0.067	0.675	0.380	0.045	0.032
r^2 CDC	0.599	-0.211	-0.014	0.197	-0.064	0.857	-0.006	0.096
INTENSITY	-1.939	0.944	-0.326	-0.047	-0.921	-0.125	-0.135	-0.023
ANNUAL PROD'N	0.496	-1.051	0.157	0.009	0.868	0.048	0.062	0.004
PROD'N AREA	-0.157	0.316	0.135	0.585	0.230	0.952	0.062	0.331
PROD'N DEPTH	0.546	-1.173	0.061	0.264	0.216	0.891	0.025	0.130
STANDING CROP	3.519	-0.789	0.186	0.432	0.347	0.769	0.083	0.236
DENSITY	1.464	-1.071	0.029	-0.103	0.081	-0.273	0.012	-0.052
WATER FLOW	-3.271	2.352	0.369	0.559	0.524	0.759	0.188	0.349
WATER REUSE	1.599	0.386	0.514	0.589	0.667	0.729	0.284	0.398
TEMPERATURE	0.699	-0.354	0.241	-0.084	0.795	-0.266	0.097	-0.042
FRESH WATER INTEN	-2.405	0.699	0.050	0.214	0.211	0.853	0.020	0.104
FISH SIZE	0.622	-0.206	0.258	0.081	0.895	0.268	0.104	0.040
HYDR. RET'N TIME	1.517	-0.330	0.313	0.274	0.471	0.393	0.154	0.165
AMMONIA	0.105	0.583	-0.073	0.564	-0.130	0.954	-0.033	0.314
TOTAL KJELDAHL N	-1.133	0.850	-0.059	0.585	-0.101	0.959	-0.027	0.329
NITRITE	0.055	0.254	0.188	0.339	0.451	0.776	0.079	0.175
NITRATE	-1.366	0.419	-0.508	0.198	-0.889	0.331	-0.232	0.111
TOTAL PHOSPHORUS	0.529	-0.128	0.082	0.535	0.149	0.930	0.037	0.295
DISS. PHOSPHORUS	-0.359	0.037	0.226	0.611	0.354	0.913	0.108	0.359
TOTAL SUSP. SOLIDS	0.069	-0.362	-0.131	0.154	-0.349	0.390	-0.054	0.078

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Exhibit 4.5:
ANOVA table of means for standard raceway, oval raceway, and circular tank salmonid fish culture facilities. Values with similar superscripts are not significantly different (P>0.05). Reported water quality data are net of source water.

Variable	Group Means			ANOVA Results		
	Raceways	Ovals	Tanks	r^2	F	P
Slope - Port 1	-0.567	-0.493	-0.573	0.066	1.46	0.2447
Slope - Port 2	-0.597	-0.503	-0.507	0.078	1.73	0.1908
Slope - Port 3	-0.600	-0.464	-0.591	0.079	1.77	0.1839
Slope - CDC	0.672	0.678	0.775	0.070	1.53	0.2284
Int. - CDC	0.037	0.184	0.031	0.007	0.14	0.8696
r2 - CDC	0.818	0.890	0.768	0.034	0.72	0.4905
Ann. Prod'n (kg)	41451	35263	13480	0.011	0.22	0.8013
Prod'n Area (m2)	186.3[a]	368.7[b]	63.3[a]	0.267	8.25	0.0010
Prod'n Depth (m)	0.89	1.00	0.79	0.053	1.15	0.3257
Standing Crop (kg)	10417[a]	8216[a]	996[b]	0.238	6.41	0.0038
Density (kg/m3)	28.0	20.6	16.8	0.098	2.23	0.1208
Avg Fish Size (g)	341.0	206.2	206.5	0.032	0.68	0.5141
Water Flow (Lps)	66.28[a]	87.06[b]	5.11[c]	0.432	15.62	0.0001
Intensity (kg/Lps)	198.7	125.3	246.8	0.039	0.83	0.4444
Water Reuse (% Flow)	0.025[a]	0.619[b]	0.069[a]	0.541	24.17	0.0001
F-Water Int (kg/Lps)	202.3	372.1	266.9	0.039	0.83	0.4415
Hydr Ret'n Time (min)	139.1[b]	337.7[a]	260.4[a]	0.218	5.73	0.0064
Temperature (C)	11.1	10.6	10.6	0.002	0.05	0.9515
Tot Kjeldahl N (mg/L)	0.871[a]	3.192[b]	1.495[a]	0.270	7.57	0.0016
Ammonia (mg/L)	0.362[a]	1.836[b]	0.757[a]	0.247	6.71	0.0030
Nitrite (mg/L)	0.068[a]	0.370[b]	0.076[a]	0.158	3.84	0.0295
Nitrate (mg/L)	-0.361	-0.873	-0.330	0.004	0.09	0.9169
Tot Phosphorus (mg/L)	0.077[a]	0.354[b]	0.158[a]	0.264	7.37	0.0018
Dis Phosphorus (mg/L)	0.027[a]	0.121[b]	0.032[a]	0.387	12.96	0.0001
Susp. Solids (mg/L)	7.007	7.076	11.148	0.041	0.89	0.4197

Exhibit 4.6:
Canonical discriminant analysis - statistical results for segmentation of three *a priori* groups of salmonid fish culture facilities.

CANONICAL AXIS	CANONICAL CORRELATION	EIGENVALUE	PROPORTION	CUMULATIVE PROPORTION
1	0.929	6.263	0.768	0.768
2	0.809	1.893	0.232	1.000

CANONICAL AXIS	LIKELIHOOD RATIO	APPROXIMATE F VALUE	NUM D.F.	DEN D.F.	PROBABILITY
1	0.048	2.437	50	34	0.0037*
2	0.346	1.420	24	18	0.2250

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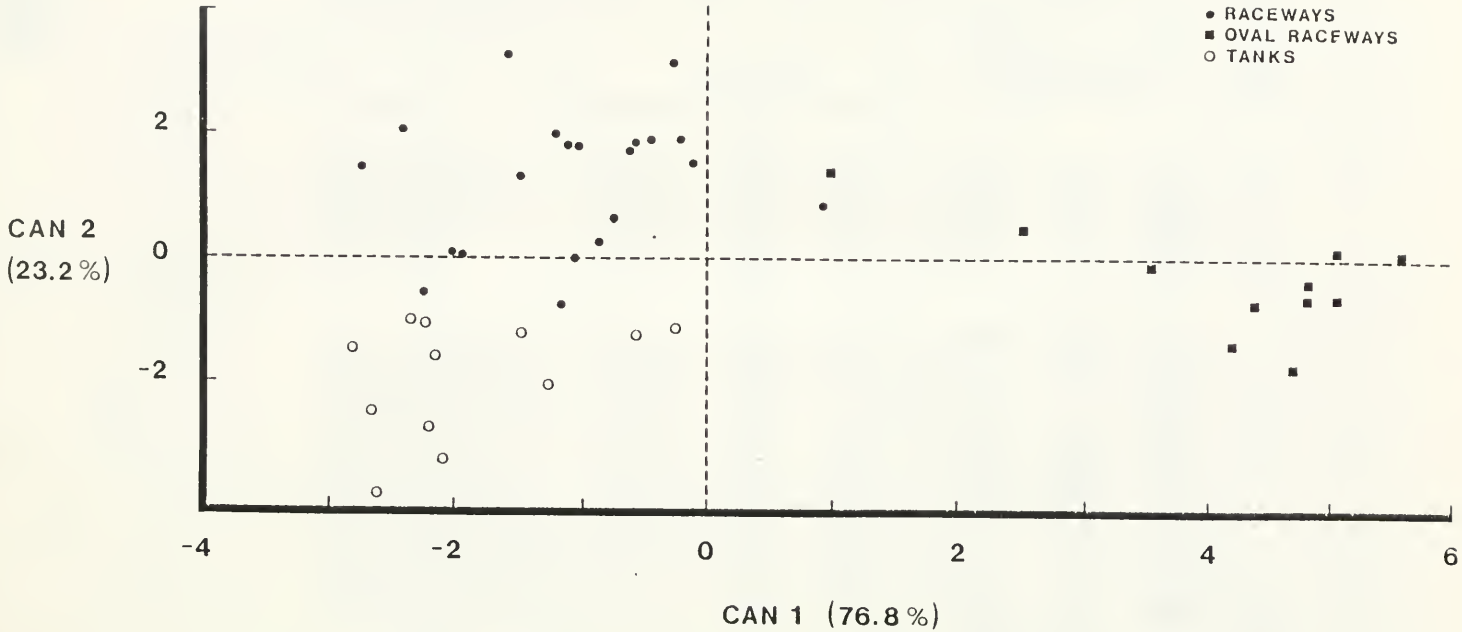

Exhibit 4.7:
Canonical discriminant analysis: Plot of canonical axes 1 and 2, identifying group segmentation among three classes of commercial trout culture facilities. Only axis 1 is statistically significant (P=0.0037). Bracketed values indicate percentage of observed variance accounted for in axis.

Exhibit 4.8:
Canonical discriminant analysis: Canonical coefficients and total, within and between canonical structures for Groups 1, 2, and 3. Only axis 1 is significant (P=0.0037).

Variable	Standardized Coefficients		Total Canonical Structure		Between Canon. Structure		Pooled Within Structure	
	CAN1	CAN2	CAN1	CAN2	CAN1	CAN2	CAN1	CAN2
m1	-0.179	0.927	0.276	0.037	0.993	0.117	0.106	0.023
m2	-0.013	-1.153	0.293	0.073	0.977	0.213	0.113	0.045
m3	-0.214	-0.231	0.303	0.002	0.100	0.006	0.117	0.001
SLOPE CDC	-0.483	-1.126	-0.194	-0.238	-0.684	-0.730	-0.075	-0.145
INTERCEPT CDC	0.380	0.028	0.083	-0.036	0.935	-0.356	0.031	-0.021
r^2 CDC	0.022	1.112	0.187	0.079	0.939	0.344	0.071	0.047
INTENSITY	-2.022	-1.970	-0.206	-0.057	-0.972	-0.236	-0.078	-0.034
ANNUAL PROD'N	-1.216	0.209	0.064	0.105	0.576	0.817	0.024	0.062
PROD'N AREA	0.210	-1.280	0.571	-0.093	0.990	-0.141	0.251	-0.065
PROD'N DEPTH	-0.834	0.071	0.232	-0.102	0.933	-0.359	0.088	-0.062
STANDING CROP	0.184	2.780	0.473	0.263	0.900	0.436	0.201	0.177
DENSITY	0.203	0.436	-0.024	0.386	-0.072	0.997	-0.009	0.239
WATER FLOW	1.474	-0.896	0.667	0.273	0.942	0.335	0.329	0.213
WATER REUSE	0.103	-0.756	0.783	-0.141	0.988	-0.155	0.429	-0.122
TEMPERATURE	-0.093	0.605	0.043	0.035	0.816	0.579	0.016	0.021
FRESH WATER INTEN	1.559	0.091	0.184	-0.124	0.862	-0.507	0.069	-0.074
FISH SIZE	0.462	-0.446	0.456	-0.321	0.852	-0.523	0.195	-0.218
HYDR. RET'N TIME	0.597	-1.051	0.482	-0.326	0.861	-0.508	0.209	-0.224
AMMONIA	0.326	-0.372	0.398	-0.181	0.930	-0.367	0.161	-0.116
TOTAL KJELDAHL N	-0.356	-0.428	-0.066	0.028	-0.937	0.350	-0.024	0.017
NITRITE	-0.172	-0.375	0.490	-0.296	0.885	-0.466	0.212	-0.203
NITRATE	0.314	1.026	0.663	-0.112	0.989	-0.146	0.314	-0.084
TOTAL PHOSPHORUS	-0.491	0.494	0.023	-0.250	0.105	-0.994	0.009	-0.150
DISS. PHOSPHORUS	0.162	0.515	0.166	0.111	0.864	0.503	0.063	0.066
TOTAL SUSP. SOLIDS	0.455	0.298	0.299	-0.465	0.594	-0.805	0.125	-0.309

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Exhibit 4.9:
Spearman correlation coefficients and statistical probabilities of finding such correlations by chance between predictor and response variables among three groups of intensive salmonid fish culture operations.

Variables	Corr. Coef.	P	Variables	Corr. Coef.	P
STANDARD RACEWAYS					
INTEN - TKN	0.462	0.035	INTEN - TP	0.372	0.097
INTEN - DP	0.584	0.005	DEPTH - TKN	0.396	0.076
CROP - TKN	0.371	0.097	FWI - TKN	0.436	0.048
FWI - DP	0.587	0.005	SIZE - TKN	0.414	0.062
SIZE - NO2	0.430	0.052			
OVAL RACEWAYS					
INTEN - TKN	0.627	0.039	INTEN - TP	0.718	0.013
INTEN - DP	0.773	0.005	CROP - NH3	0.582	0.060
CROP - TKN	0.600	0.051	CROP - TP	0.564	0.071
CROP - DP	0.791	0.004	DENS - NH3	0.545	0.083
FLOW - NO3	0.733	0.010	REUSE - NO3	0.590	0.056
FWI - TKN	0.609	0.047	FWI - TP	0.527	0.096
FWI - TP	0.836	0.001			
CIRCULAR TANKS					
INTEN - NH3	0.804	0.002	INTEN - TKN	0.664	0.019
INTEN - TP	0.776	0.003	DEPTH - TKN	0.790	0.002
DEPTH - TP	0.580	0.048	DEPTH - TSS	0.524	0.080
CROP- TKN	0.545	0.067	CROP - TP	0.727	0.007
DENS - TP	0.552	0.063	FWI - NH3	0.734	0.007
FWI - TKN	0.671	0.017	FWI - TP	0.776	0.003
SIZE - TKN	0.510	0.090	SIZE - NO2	0.497	0.099
SIZE - TP	-0.508	0.092	SIZE - DP	0.601	0.039

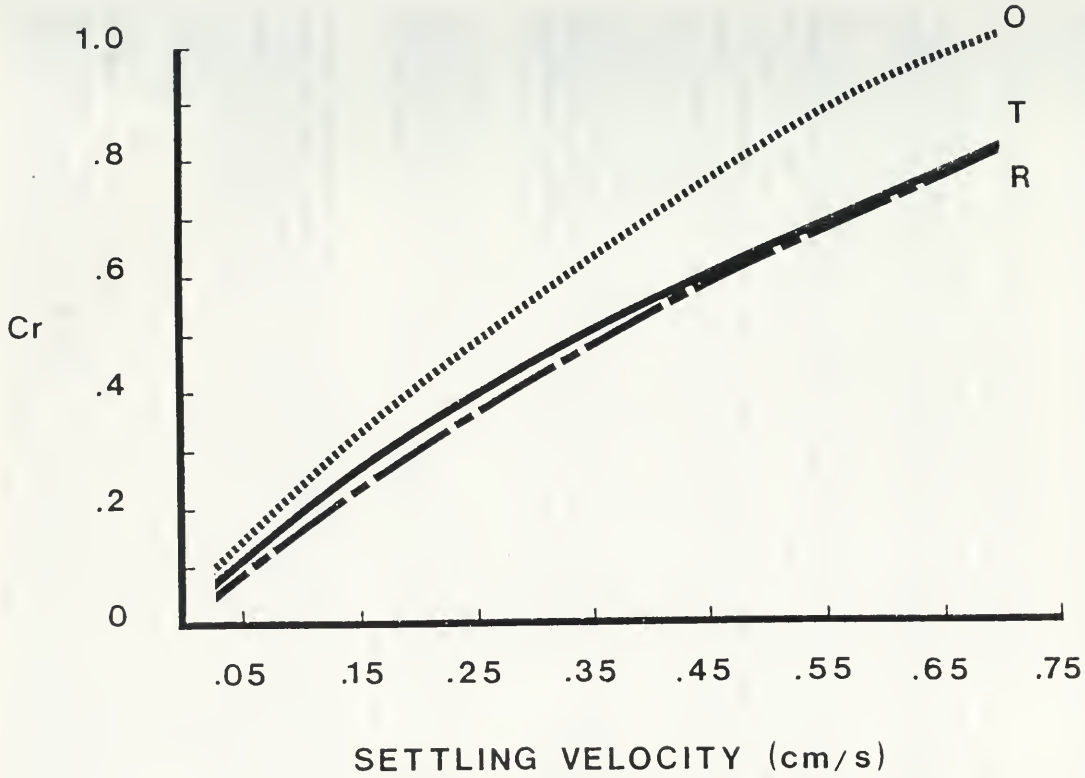

Exhibit 4.10:
Settling velocity profiles for suspended solids from intensive trout production facilities. R = standard raceways; O = oval raceways; T = circular tanks. All slopes are not significantly different ($P>0.05$), however, the intercept of curve O is significantly less than those of curves R and T ($P<0.01$). For an explanation of this curve, see Section 3.1.

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5.0 STATUS OF AQUACULTURE EFFLUENT TREATMENT IN ONTARIO

The 44 farms included in Groups 1, 2, and 3 comprise a substantial proportion of the commercial trout producers in Ontario. Of these operators, more than half utilize some means of effluent treatment prior to discharging process water from their facilities. Sedimentation technologies are applied exclusively at these facilities; the use of technologically advanced filtration equipment for effluent treatment has not been witnessed on a commercial scale in the province.

5.1 Aquaculture Settling Facilities in Ontario

Four principal gravitational solids removal strategies are used: (1) in-raceway settling basins; (2) external, rectangular basins; (3) external ponds; and (4) external circular basins.

In-raceway settling consists of allocating a portion of the raceway unit for settling, usually at the downstream end. Screens are typically used to keep fish out of the settling area; however, it is not uncommon for a few fish to be present in the quiescent zone. In some instances, overflow or underflow weirs are used to introduce water to the settling zone. In virtually all cases, flow is introduced across the entire width of the raceway. Few operators utilize full-width discharge weirs, however, as overflow discharge standpipes tend to be more common.

Due to the physical layout of some fish culture facilities, the major stream of process water is not treated within the culture unit but rather it is subsequently treated in a separate sedimentation basin. Such units must be large enough to accommodate the entire farm process flow. In these instances, rectangular concrete basins, earthen ponds, and/or circular basins are used.

External rectangular basins are often much like raceways, however, they are frequently wider and shorter. Flow is usually introduced through a modified pipe inlet, not dissimilar from those inlet structures depicted in Exhibit 3.5. The use of submerged, wide-top weirs is limited. Outlet structures vary between full-width overflow weirs and vertical standpipes.

Earthen pond settling basins <u>were</u> the accepted effluent treatment process of the past for fish culture facilities. While most ponds have been designed with a substantial surface area for settling, poor inlet and outlet design, excessive depth, and the inability to clean solids from the bottom render them inefficient in many applications. These design flaws generally stem from out-dated criteria mandating a specific retention capacity within the pond. Moreover, point source inlet and outlet structures are the norm, thereby exacerbating the inherent inefficiency of ponds.

In recent years, the use of circular settling basins has evolved in aquaculture. These basins are typically constructed of galvanized steel silo walls, which are laid into a concrete pad. A single pipe inlet conventionally rises from below ground at the centre of the tank. A distribution baffle, constructed of a perforated steel or plastic barrel, is usually placed over the

inlet pipe, extending from the floor to the surface of the basin. This baffle serves to reduce turbulence and distribute the flow radially across the tank. The outlet from the basin most commonly consists of perforated drainage tile which is moored at the basin surface around the perimeter of the tank. In spite of the use of this effective design, some operators utilize circular basins with a peripheral inlet and a central drain. In the latter cases, internal baffles are often used to control the flow of water within the basin. This inward flow approach is comparatively inefficient.

5.2 Effectiveness of Existing Treatment Operations

During the field survey component of this investigation, specific design and operations data were collected from existing effluent treatment facilities at fish culture operations. Only those facilities from which it was possible to obtain water samples from the treatment influent and effluent flows, and where the dimensions and total water flow through the treatment unit could be quantified, were included in this portion of the study. In all, 26 treatment units, at 24 farms, were sampled. The 17 observed variables are defined in Exhibit 5.1.

A priori segmentation was used to classify the different treatment methods prior to statistical analysis. Since earthen settling ponds act as a nutrient sink (Westers 1989), and since they introduce substantial variability due to the inherent biological activity within, pond treatment units have been eliminated from this analysis. Moreover, data were collected from only two earthen settling ponds during the field investigation. MANOVA was used to identify differences between the three remaining groups: i.e. in-raceway settling units; external, rectangular basins; and external, circular basins. The analysis revealed a significant difference between groups (P=0.051).

Multivariate Analysis of Variance
Test Criteria & F Approximation

Statistic	Value	F	Nm DF	Den DF	Prob.
Wilks' Lambda	0.00986	2.6671	34	10	0.051

Using univariate ANOVA, coupled with Student-Newman-Keuls multiple range tests, between-group differences were found to be associated with hydraulic loading, inlet area, outlet weir rate, and NH_3 removal. For the most part, however, no differences in removal efficiency of the seven water chemistry variables were observed between the three different types of treatment facilities (Exhibit 5.2).

The data indicate that the removal efficiency of TSS from aquaculture effluents is poor, averaging only 29.5% in in-raceway settling facilities, 31.7% in external, rectangular basins, and 15.5% in external circular basins. Similarly, removal of total phosphorus is also poor, averaging only 0.8% in in-raceway treatment units and 38.3% in external rectangular basins. For dissolved phosphorus, effluent concentrations were greater than influent concentrations in all treatment designs (Exhibit 5.2), confirming that a portion of particulate

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phosphorus quickly becomes solubilized within the system. Complete data sets for all treatment units are presented in Appendix IV.

Examination of the design and operating parameters for these effluent treatment facilities provides several explanations for the overall poor level of performance. In spite of various recommendations which suggest that overflow rates be in the range of 40 to 80 $m^3/m^2/d$ for aquaculture clarifiers (note that this is not necessarily a recommendation of this report; see Section 7), average overflow rates were found to surpass this range in 17 of 26 cases. Values ranging from 85.9 $m^3/m^2/d$ in external rectangular basins to 344.3 $m^3/m^2/d$ in external circular basins were observed (Exhibit 5.2). Notice, too, that external rectangular basins have higher average removal efficiencies for TSS and TP than do in-raceway and external circular basins; the difference, however, is not statistically significant. This difference is likely a reflection of overflow rate, although certainly not exclusively. Outlet weir rates which exceed design recommendations by approximately 2 to 6 fold were observed at 19 of the 26 treatment facilities (Exhibit 5.2).

Since all three groups were found to display similar treatment efficiencies, design and operations variables were correlated with water chemistry variables in search of meaningful relationships within the total data set. Correlation coefficients and statistical probabilities are presented in Exhibit 5.3. The cross-sectional area of the inlet zone and the total surface area of the settling basin hold the most meaningful correlations with respect to treatment efficiency. Correlation coefficients are greater between Vo and settling performance than between outlet weir rate and settling performance, suggesting that overflow rate is the more critical of these two design factors.

Basin surface area is highly correlated with both TSS removal (P=.069) and TKN removal (P=.072). Negative correlation coefficients indicate that an increase in surface area is concomitant with enhanced removal of TSS and TKN. Recall from Exhibit 5.1 that the water chemistry data assessed in this analysis consist of ratios of treatment effluent to treatment influent -- the lower the number, the lower the effluent concentration relative to the influent concentration. The cross sectional area of the inlet zone is also correlated with TSS removal (P=.075), and with nitrite removal (P=0.001). Similarly, negative correlations imply that removal of these components increases as cross sectional area of the inlet zone increases, suggesting reduced inlet energy and turbulence. Conversely, however, removal of dissolved phosphorus is enhanced (P=.015) when inlet area is reduced (Exhibit 5.3), perhaps due to greater short-circuiting, which reduces retention time for a portion of the flow and thus decreases contact time for solubilization of nutrients within the settling basin.

Three variables (TSS, TKN, TP) are negatively correlated with hydraulic retention time (P<.092), suggesting that increased retention time improves settling efficiency. This is most certainly a reflection of the impact of basin surface area on settling and not due to retention time. Retention time is the quotient of the volumetric flow rate divided by basin volume and, therefore, an increase in volume leads to an increased retention time. Increased volume, however, is generally attributed to increased area since, in aquaculture, basin depths are generally relatively constant at 0.7 to 1.2 metres. Moreover, this

explanation is substantiated by the fact that improved removal of the same parameters is correlated with basin area (Exhibit 5.3).

Interestingly, basin depth was found to be highly correlated with enhanced removal of ammonia (P=.017) and TKN (P=.002). No correlation exists, however, between depth and total suspended solids removal (P=.186), supporting the concept that particulate matter in aquaculture effluents exhibits discrete settling behaviour. Lastly, a significant negative correlation (P=.007) exists between average fish size and total suspended solids removal, suggesting that solids removal is facilitated in production units rearing larger fish (Exhibit 5.3).

5.3 Chapter Summary - Principal Findings

5.3.1 All three different treatment facility designs display similar treatment efficiencies. Moreover, all performed relatively poorly with respect to TSS and TP removal. Effluent concentrations of DP increase as water passes through the treatment facility in all three treatment designs.

5.3.2 Poor performance is likely related to a combination of operational and design flaws; namely, excessive overflow rates and outlet weir rates, and improper inlet and outlet structure designs. Given high design overflow rates and for the most part only poor to good treatment facilities, the applicable scaling factor for determination of an appropriate performance overflow rate becomes quite large. Consequently, poor treatment efficiency is expected.

5.3.3 TSS removal is highly correlated with settling unit surface area. Since depth is relatively uniform across treatment facilities, this suggests that TSS removal is related to overflow rate; i.e. as area increases and depth is held constant, overflow rate decreases. While this finding is not supported by the correlation data for TSS and overflow rate, it was found to be highly significant in data collected at land-based New Brunswick salmon smolt production operations.

5.3.4 TSS removal is highly correlated with average fish size, suggesting that solids settling is enhanced in operations raising large fish. The smaller feed and fecal pellets associated with small fish reduce settling velocities and, therefore, make effluent treatment via sedimentation somewhat more difficult. Given similar hydraulic flows and production intensities, a system producing small fish will require a larger settling facility (area) to achieve the same level of performance as an operation raising larger fish.

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Exhibit 5.1:
Definition and units of measure for 17 effluent treatment variables observed and recorded during site visits. The abbreviated name used in the results section is also presented.

Variable Name	Units	Abbr.	Definition
Design/Operational Variables			
Settling Area	(m^2)	AREA	Total surface area of the settling unit.
Hydraulic Load	(m^3/d)	Q	Total water flow through treatment unit on a daily basis.
Overflow Rate	(m^3/m^2/d)	Vo	Calculated; Vo = Q/AREA.
Inlet Area	(m^2)	INLET	Cross sectional area of inlet zone of the settling unit.
Outlet Weir Rate	(m^3/m/d)	OWR	Daily volumetric flow of water per unit length of outlet weir.
Hydr. Ret'n Time	(min)	HRT	Theoretical retention time of water in settling unit.
Depth	(m)	DEPTH	Average depth of settling unit.
Slope of CDC	--	mCDC	Slope of cumulative distribution solids settling curve.
Intercept of CDC	--	INTPT	Intercept of cumulative distribution solids settling curve.
Fish Size	(g)	SIZE	Average weight of individual fish in prod'n unit feeding settling unit.
Water Chemistry Variables			
Tot. Susp. Solids	--	TSS	These data are dimensionless. They are ratios of the effluent concentration of the parameter to the influent concentration. A number less than 1.0 indicates a net loss of that parameter via settling.
Total Ammonia	--	NH3	
Tot. Kjeldahl N	--	TKN	
Nitrite	--	NO2	
Nitrate	--	NO3	
Total Phosphorus	--	TP	
Diss. Phosphorus	--	DP	

Exhibit 5.2:
ANOVA table of mean design/operational factors and treatment efficiency for in-raceway, external rectangular, and external circular settling basins at intensive salmonid culture facilities. Values having the same superscript are not significantly different.

Variable	In-raceway (n=11)	Ext. Rect. (n=5)	Ext. Circ. (n=8)	F Ratio	Prob.
Design/Operational Variables					
Basin Area (m^2)	27.4	29.9	28.9	0.880	0.430
Hydraulic Load (m^3/d)	6251^{a}	1486^{ab}	1060^{b}	3.393	0.053
Overflow Rate ($m^3/m^2/d$)	269.5	85.9	344.3	2.307	0.124
Inlet Area (m^2)	3.17^{a}	0.96^{bc}	0.30^{c}	19.93	0.000
Out. Weir Rate ($m^3/m/d$)	2062^{a}	1081^{ab}	945^{b}	3.308	0.056
Hydr. Ret'n Time (min)	9.75	27.7	42.1	1.357	0.279
Basin Depth (m)	0.93	0.72	1.08	2.289	0.126
Slope CDC	.6210	.7851	.8253	2.269	0.128
Intercept CDC	.0057	.0871	.1639	0.452	0.643
Average Fish Size (g)	216	242	159	1.643	0.217
Effluent Treatment Efficiency Variables (see Note)					
Tot. Susp. Solids	0.705	0.683	0.845	0.176	0.839
Ammonia	0.995^{ab}	2.097^{a}	0.870^{b}	2.892	0.078
Tot. Kjeldahl N	0.894	0.999	0.816	0.500	0.614
Nitrite	0.954	1.229	1.800	1.632	0.219
Nitrate	0.981	1.753	1.872	1.349	0.281
Total Phosphorus	0.992	0.617	1.016	1.044	0.370
Diss. Phosphorus	1.569	1.808	1.067	1.319	0.289

N.B. Effluent treatment efficiency variables are dimensionless values; they represent the ratio of effluent to influent concentrations. A number less than 1.0 signifies removal of that contaminant from the effluent stream.

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Exhibit 5.3:
Matrix of correlation coefficients and statistical probabilities (P) between sedimentation unit design/operations factors and treatment efficiency with respect to seven water quality parameters (n=24).

Design & Operating Parameters \ Water Chemistry Parameters	TSS	NH3	TKN	NO2	NO3	TP	DP
AREA	-.3112 P= .069	-.1870 P= .191	-.3073 P= .072	.0345 P= .436	.1692 P= .215	-.2615 P= .109	.0886 P= .340
Q	-.2246 P= .146	-.1347 P= .265	-.1303 P= .272	-.1063 P= .311	.0674 P= .377	-.1110 P= .303	.0375 P= .431
Vo	.2438 P= .125	.2026 P= .171	.2408 P= .129	-.1627 P= .224	-.0945 P= .330	.2491 P= .120	.0553 P= .399
INLET	-.3025 P= .075	.1717 P= .211	-.0044 P= .492	-.5813 P= .001	-.2463 P= .123	-.0627 P= .385	.4442 P= .015
OWR	-.0155 P= .471	.0456 P= .416	.1285 P= .275	-.1299 P= .273	-.2345 P= .135	.0175 P= .468	.0847 P= .347
HRT	-.2809 P= .092	-.2651 P= .105	-.3710 P= .037	.1944 P= .181	.1544 P= .236	-.2823 P= .091	-.0908 P= .336
DEPTH	-.1910 P= .186	-.4327 P= .017	-.5575 P= .002	.1045 P= .313	.0941 P= .331	-.1969 P= .178	-.2542 P= .115
mCOC	-.0107 P= .480	.0525 P= .404	-.1121 P= .301	.0615 P= .388	-.1283 P= .275	.0854 P= .346	-.0267 P= .451
INTPT	-.2077 P= .165	-.1389 P= .259	-.0572 P= .395	-.0817 P= .352	-.2653 P= .105	.1444 P= .250	-.1276 P= .276
SIZE	-.4960 P= .007	-.0916 P= .335	-.2252 P= .145	.0007 P= .499	-.0064 P= .488	-.2553 P= .114	.1752 P= .206

N.B. A negative correlation coefficient implies improved treatment efficiency due to an increase in the corresponding design/operations variable. Recall that the treatment data are ratios of effluent/influent concentrations.

6.0 IMPLEMENTATION OF AQUACULTURE EFFLUENT TREATMENT

6.1 Commercial Fish Production Facilities in Ontario

Across Ontario, three principal fish culture production units exist, and the decision to construct one over the others is generally based upon the individual preference of the aquaculturist. Circular tanks are often selected for their self-cleaning qualities; standard raceways for their ease of management; oval raceways for their reduced concrete content and the perceived benefits of extended water use. Other decision factors include familiarity with a given system; i.e. fish farmers often construct a facility which is similar to a neighbour's.

Throughout the investigation oval raceway production facilities have consistently stood out as unique production facilities, different from standard raceway and circular tank operations with respect to several production and water quality parameters. Oval raceways generally incorporate a larger production area, utilize more water reuse, and produce an effluent of poorer quality than the other production units (Exhibit 4.5). With respect to solids settling behaviour, oval raceways produce a cumulative distribution sedimentation curve which has a significantly greater elevation (Exhibit 4.10), implying that solids removal via settling is more difficult in these facilities than in standard raceways and circular tank operations. From a productivity perspective, however, oval raceway systems seem to offer no additional benefits. Most importantly, these units do not offer extended water use. That is, productivity, in terms of carrying capacity of fish per unit water flow (kg/Lps), is statistically similar (P=.4415) in standard raceways, oval raceways, and circular tanks (Exhibit 4.5).

This finding suggests that, for a given volumetric flow of water, a relatively constant amount of fish can be produced. Naturally, this amount will differ due to the experience of the culturist, and will increase if additional factors are introduced, such as liquid oxygen injection and/or recirculation with biofiltration for ammonia removal. For the most part, however, productivity is not influenced by the use of standard raceways, oval raceways, or circular tanks. Consequently, any tangible benefits related to using oval raceway culture units must derive from other factors, which were not observed and recorded within the scope of this investigation. Such factors may include: faster growth, improved fish health, ease of management, reduced capital and/or operating costs, and so forth.

In all culture facilities examined, culture intensity (kg fish/Lps), standing crop (kg fish), and average fish size (g) are significantly correlated with many aspects of effluent quality (Exhibit 4.9). Intuitively, this is logical since an increase in any one of these factors necessarily translates to an increase in feed ration and, consequently, poorer water quality. Feed input <u>is</u> responsible for deterioration of water quality. Therefore, feeding strategies must be considered as an important management tool for effluent quality control. While feed presents the source of the pollution problem, specific feed-related factors (i.e. feed brand and type, and feeding method) were not found to impact upon the quality of effluent or effectiveness of treatment. While this may not be entirely plausible, it does suggest that feed-related factors are subordinate to the polluting influence of facility design and culture management practice.

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6.2 Design of Effluent Treatment Facilities for Intensive Salmonid Aquaculture

For most commercial-scale intensive salmonid aquaculture operations, solids removal via gravity settling remains the best available technology. Moreover, since total phosphorus removal is significantly correlated with total suspended solids removal (Mudrak 1981; Stechey 1988; Appendix III), gravity settling is also recommended for reduction of effluent concentrations of phosphorus. Specific phosphorus removal technologies (i.e. addition of metal-salts, chemical polymers, and/or lime to promote phosphorus precipitation; biological uptake into cell tissue) are not warranted in aquaculture due to the dilute nature of the wastewater stream and the relative expense of these processes.

Overflow Rate. As stated in Section 3.2.4, overflow rate (Vo) must be the foundation of design for solids settling units. Based upon the cumulative distribution curves for solids settling in standard raceway, oval raceway, and circular tank production facilities, relationships between overflow rate and solids removal efficiency can be projected. These relationships are graphically presented in Exhibit 6.1. The UMA Engineering study (1988) recommends design overflow rates ranging between 40 and 80 $m^3/m^2/d$ (0.046 - 0.092 cm/s). This means that, for every Imperial gallon of water flowing through the treatment unit each minute (IGPM), 1.75 to 3.50 square feet of settling basin surface area must be provided. Theoretically, for overflow rates in this range, TSS removal efficiency varies between 86% and 94% (Exhibit 6.1). In similarly designed treatment units, however, removal efficiency is better for standard raceway and circular tank production operations due to differences in the settling behaviour of suspended particulate material in oval raceway effluent.

Recall, however, that turbulence must be accounted for in design by applying an appropriate scaling factor, as presented in Exhibit 3.4. In reality then, solids removal in the range of 86% to 95% is unlikely. For theoretical solids removal efficiencies in this range, and assuming that basin design and performance is "very good," the data in Exhibit 3.4 recommend that a scaling factor between 2.2 and 3.6 be applied. The net result will be a reduced efficiency rating for the design overflow rate. This is best explained using the following example.

Let's assume that an in-raceway settling basin has been designed using proper inlet and outlet structures, a <u>design overflow rate</u> equal to 40 $m^3/m^2/d$ (0.046 cm/s) based upon the actual surface area of the settling basin and the hydraulic flow, and that the design is "very good." In theory, the curve in Exhibit 6.1 suggests that TSS removal efficiency will equal 94.5%. From Exhibit 3.4, we determine that a scaling factor of 3.6 must be used to adjust this performance projection. Consequently, the <u>performance overflow rate</u> is more appropriately equal to 0.166 cm/s (0.046 x 3.6) or 143 $m^3/m^2/d$. Going back to the plot in Exhibit 6.1, we see that, in reality, the projected efficiency of this system is closer to 86%.

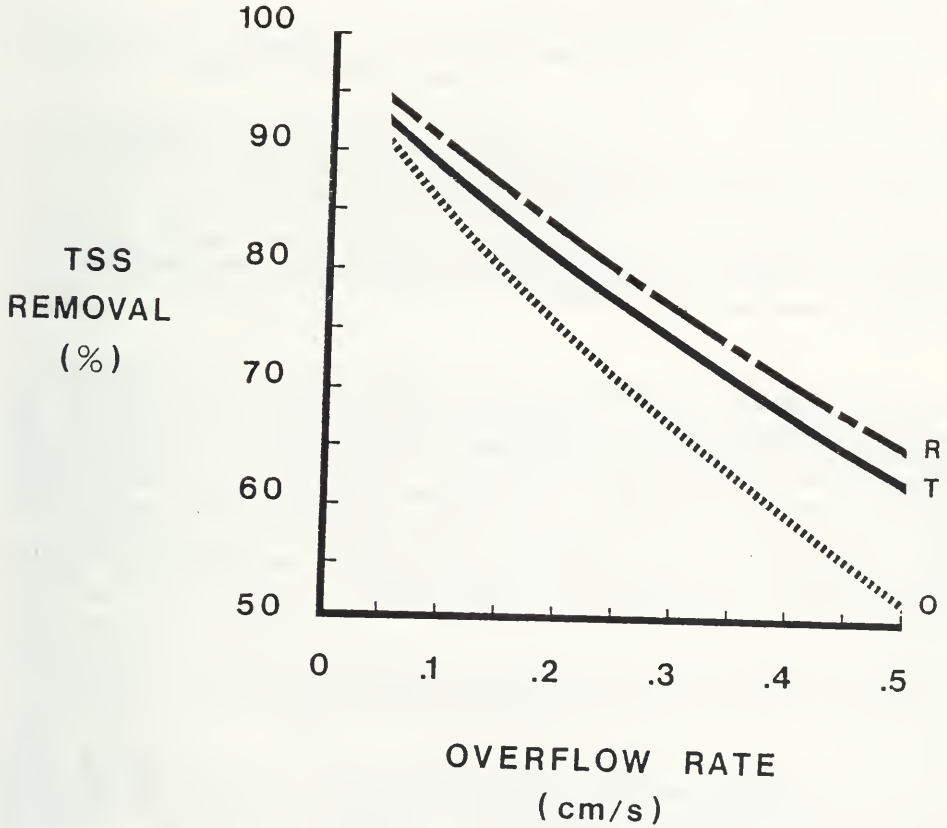

Exhibit 6.1:
Theoretical average performance curves for efficiency of total suspended solids removal via gravitational settling from the discharged effluent of three types of intensive trout culture facilities. R = standard raceways; O = oval raceways; T = circular tanks.

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Therefore, when designing settling basins for aquaculture operations, an iterative approach is necessary:

(1) The surface area required for settling is calculated based upon the design overflow rate (see Section 6.4) and the hydraulic loading rate of the operation.

(2) The theoretical efficiency of this design is determined using the data plotted in Exhibit 6.1 for the appropriate fish culture facility.

(3) A scaling factor must be selected from Exhibit 3.4, based upon this design. This scaling factor is used to adjust the design overflow rate to enable a realistic projection of basin efficiency.

(4) If the effectiveness of solids removal is too inefficient to meet effluent discharge criteria, then the process must be repeated from Step 1 using a lower overflow rate.

At existing operations, the design overflow rate can be calculated by dividing the area of the settling basin into the hydraulic flow rate of the basin. Then, using Exhibit 6.1, a theoretical removal rate can be determined for the treatment facility. Next, using Exhibit 3.4, an appropriate scaling factor can be selected to calculate the performance overflow rate, and to project a more realistic level of efficiency. Experiential judgement will be required to classify the overall level of basin performance such that an appropriate scaling factor from Exhibit 3.4 can be selected and applied. If the projected level of efficiency is insufficient to meet discharge criteria, the area of the settling basin will need to be increased (or the hydraulic load decreased) to improve performance.

In all settling basins, the average horizontal fluid flow velocity must be maintained below 2 to 4 cm/s to ensure that scour problems do not arise.

Inlet Structures. Proper inlet design is critical for minimizing inlet velocity, turbulence, and hydraulic short-circuiting. The specific design of the inlet structure, however, will depend upon the type of treatment facility being used. In all cases, the inlet should be designed such that fish from the production area of the culture facility do not enter the settling basin.

For in-raceway settling basins, there is no need for an inlet structure, per se. Instead, simply screening off a section of the raceway at the downstream end provides for effective introduction of water to the quiescent settling zone. It is imperative, however, that all air diffusers be kept upstream of the fish retaining screen at a distance of approximately 2 times the depth of the water column. This is necessary since the rising air bubbles create large convective cells having a circular mixing motion over this region. The screen material (usually semi-rigid plastic) must be sufficiently small to restrict the passage of fish into the settling zone.

If external rectangular basins are used, it is important to distribute the inlet flow across the entire width of the basin, and to achieve this with minimal energy input. A submerged, wide-top weir with chamfered edges, which extends across the full width of the settling basin, is most appropriate. The degree of submergence should be approximately 15% of the basin depth; i.e. in a 1 metre deep basin, the weir should be 85 cm tall. Since some turbulence is still introduced with this inlet structure, the settling zone should be lengthened to account for any reduction in efficiency due to the inlet. A typical length increment is equal to the basin depth.

For external circular basins, process water should enter the basin at the centre, ideally from below the basin floor. The inlet pipe should be enclosed within a concentric perforated baffle, designed to reduce inlet velocity and distribute the flow radially through the full depth of the basin. The inlet turbulence can be accounted for by adding 0.25 times the basin depth to the basin diameter. Moreover, since circular tanks come in standard sizes, the designer of a circular settling basin will be wise to use the standard tank size which is larger than that recommended in design calculations, as opposed to a tank slightly smaller than required.

Outlet Structures. For all settling basins, an overflowing outlet weir is most appropriate for gently drawing off clarified effluent from the treatment unit. This structure must be designed such that the clear water is skimmed off the top of the basin; hence the overflow design. To minimize the entrainment of fine particulate material in the rising discharge flow, it is important to maximize the length of the outlet weir.

For in-raceway and rectangular settling basins, at a minimum the weir must extend across the entire width of the basin. The outlet weir rate ($m^3/m/d$ or IGPM/foot weir length) can be measured and used as an indicator of the entrainment effect. If the weir rate is greater than 400 $m^3/m/d$ (18.6 IGPM/ft), then the settling zone should be lengthened by 1.5 times the basin depth in compensation. For weir rates between 350 and 400 $m^3/m/d$ (16.3 to 18.6 IGPM/ft), the additional length requirement is 1.3 times basin depth, and for weir rates below 350 $m^3/m/d$ (16.3 IGPM/ft), the added length need only be equal to the basin depth. Finally, in circular settling basins, the overflow weir should extend around the periphery of the basin. Since the circumference of circular tanks is large in relation to the width of similarly sized rectangular basins, compensation for outlet entrainment effects is generally not required in circular basins.

In most existing effluent treatment facilities, overflow standpipes are used for outlet structures. These can be readily upgraded at minimal expense. Two alternatives exist. Placement of an overflow weir constructed of damboards or stoplogs immediately upstream of the standpipe will provide the necessary weir. To ensure an overflow action, the damboards should be used to control tank water level and the standpipe should be cut approximately 6 to 10 cm shorter. Alternatively, a T-fitting can be placed over top of the existing stand pipe. From each end of the T, a halved pipe is cemented into place, extending from one side of the basin to the other. This configuration essentially provides a double-width weir, since water now overflows on both the upstream and downstream

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sides of the halved pipe. Effluent is discharged through the standpipe as before. In adapting overflow weirs, however, care must be taken to ensure that the weir is level, thereby ensuring that water flow is uniform across the entire weir length.

6.3 Projected Production of Phosphorus and Solids from Intensive Fish Culture Facilities

Operations data collected during the field study have provided a quantitative understanding of standing crop biomass and fish production intensities based upon water use. Production intensity represents the weight of fish in the tank per unit water flow (kg fish/litre per second of source water flow). Standing crop is the average total weight of fish in the production unit(s). These field data can be applied, in conjunction with the waste production factors defined in Section 6.4, to project average daily concentrations of TSS, TP, and DP in untreated fish production effluent. Moreover, projections can be generated for the three groups of production facilities.

For each group, the average standing crop (kg fish) was used as a starting point. A feeding rate of 1.2% body weight per day was assumed, based on production data which show that the average size of individual fish ranged between 204 and 340 grams, and was not significantly different ($P>0.05$) between groups. The mean fresh water intensity, and the 95% confidence limits around this mean, were incorporated into the model as an indication of production intensities. From these data, an average influent flow rate was calculated, and then, using the waste production factors for TSS, TP, and DP, average daily concentrations of these pollutants in the production effluent were projected. These projected values are compared with observed values in Exhibit 6.2.

For all three groups, variability exists between observed and expected concentrations of pollutants in the effluent. Among the three pollutants, this variability is greater for total and dissolved phosphorus than for solids concentrations. In some cases, projected values are two- to three-fold greater than observed values. Solids modelling is reasonably accurate for standard raceways and circular tanks, but it over-estimates the concentration of effluent solids in oval raceways. Conversely, phosphorus modelling is reasonably accurate for oval raceways, but is over-estimated in standard raceways and circular tanks (Exhibit 6.2).

Oval raceways produce the highest expected concentration of TSS, TP, and DP among the three groups while standard, flow-through raceways produce the lowest concentrations. Indeed, observed data confirm that TP and DP concentrations are significantly lower ($P<0.002$) in standard raceway and circular tank operations (Exhibit 4.5). Circular tank operations were observed to produce the greatest concentration of TSS, however, field observations reveal no significant difference between the three groups ($P=0.4197$).

Possible factors which contribute to the variability between predicted and observed values may include the use of "fresh water intensity" as a model input. In group comparisons, FWI was not found to differ between groups ($P=0.4415$),

however, individual groups means were incorporated into the model. As well, for individual pollutants, the reliability of the waste production factors may be suspect, especially for phosphorus. Solids modelling is comparatively simple; the only critical factor is the overall digestibility of the diet -- a component which is well quantified by feed manufacturers. Total and dissolved phosphorus production, however, is largely influenced by the quality and quantity of phosphorus in the diet, which is subject to change due to variations in feed ingredients. Moreover, the range of production factors for phosphorus compounds in published literature is greater than that for total suspended solids, thereby affirming the complexity of nutrient load modelling. Lastly, the assumption of a feed rate of 1.2% body weight per day is valid for modelling, however, one cannot assume that this feed rate was applied in all fish culture facilities on the specific days when field samples were collected.

Assuming, however, that these modelled waste production figures present best available data, then these data can be applied in conjunction with effluent treatment efficiency figures to generate numbers reflecting the anticipated quality of final discharged effluent from aquaculture operations. The data provided in Exhibit 6.2 offer a margin for error since, for nearly all pollutants and fish culture facilities, the projected values are greater than those values observed during field monitoring.

6.4 Projected Performance of Effluent Treatment Facilities

When the nature and composition of aquacultural wastes are considered in design, aquacultural treatment systems can be particularly effective in clarification of discharged effluent. Moreover, since the removal of total phosphorus is positively correlated with removal of suspended solids, a reduction in the latter necessarily translates into a reduction in the former.

Operational data from existing fish hatchery treatment units in the United States have been compiled (Exhibit 6.3). Settleable solids (SS) removal in excess of 90% is readily achieved, and greater than 80% removal of total suspended solids (TSS) is reported (Mudrak 1981; McLaughlin 1981). Note that the design overflow rates for these facilities range between 21.4 and 120.0 $m^3/m^2/d$ (0.025 to 0.139 cm/s). Total phosphorus removal via sedimentation in concrete clarifiers is reported for three fish culture stations in Pennsylvania. Oswayo FCS, Tionesta FCS, and Big Spring FCS report average reductions of total phosphorus in discharged effluent equalling 62%, 68%, and 77%, respectively (Mudrak and Stark 1981; Mudrak 1981).

Regression analysis of the data presented by Mudrak (1981) for total suspended solids and total phosphorus removal provides the following relationship:

$$\% \text{ TP Removal} = 0.838 \times \% \text{ TSS Removal} - 4.679 \qquad r^2 = 0.936 \quad (n=9)$$

Using the TSS and TP production rates in Ontario fish culture operations (see Exhibit 6.2), and applying the removal efficiencies for TSS in properly designed clarifiers (see Exhibits 3.4 and 6.1), the likely concentration of discharged pollutants from commercial fish culture operations can be projected (Exhibit 6.4).

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Exhibit 6.2:
Projected and observed concentrations of TSS, TP, and DP in untreated fish culture effluent assuming a daily feed ration of 1.2% body weight. Data for standing crop and fresh water intensity are from field observations.

	Lower C.L.	Mean	Upper C.L.
STANDARD RACEWAYS			
Standing Crop (kg)		10417	
Feeding Rate (% body weight/day)		1.2	
Daily Feed Ration (kg)		125.0	
Fresh Water Intensity (kg/Lps)	99.1	202.3	305.5
Average Flow Rate (Lps)	105.1	51.5	34.1
TSS Prod'n @ 300 g/kg Feed (kg)	37.50	37.50	37.50
Projected Avg. Daily [TSS] (mg/L)	4.13	8.43	12.73
Observed [TSS] (mg/L)	4.20	7.01	9.82
TP Prod'n @ 7.6 g/kg Feed (kg)	0.950	0.950	0.950
Projected Avg. Daily [TP] (mg/L)	0.105	0.214	0.322
Observed [TP] (mg/L)	0.053	0.077	0.102
DP Prod'n @ 2.2 g/kg Feed (kg)	0.275	0.275	0.275
Projected Avg. Daily [DP] (mg/L)	0.030	0.062	0.093
Observed [DP] (mg/L)	0.012	0.027	0.041
OVAL RACEWAYS			
Standing Crop (kg)		8216	
Feeding Rate (% body weight/day)		1.2	
Daily Feed Ration (kg)		98.6	
Fresh Water Intensity (kg/Lps)	196.9	372.1	547.4
Average Flow Rate (Lps)	41.7	22.1	15.0
TSS Prod'n @ 300 g/kg Feed (kg)	29.58	29.58	29.58
Projected Avg. Daily [TSS] (mg/L)	8.20	15.50	22.81
Observed [TSS] (mg/L)	4.18	7.08	9.97
TP Prod'n @ 7.6 g/kg Feed (kg)	0.749	0.749	0.749
Projected Avg. Daily [TP] (mg/L)	0.208	0.393	0.578
Observed [TP] (mg/L)	0.138	0.354	0.570
DP Prod'n @ 2.2 g/kg Feed (kg)	0.217	0.217	0.217
Projected Avg. Daily [DP] (mg/L)	0.060	0.114	0.167
Observed [DP] (mg/L)	0.072	0.121	0.170

Exhibit 6.2: (cont'd)
Projected and observed concentrations of TSS and TP in untreated fish culture effluent assuming a daily feed ration of 1.2% body weight. Data for standing crop and fresh water intensity are from field observations.

	Lower C.L.	Mean	Upper C.L.
CIRCULAR TANKS			
Standing Crop (kg)		996	
Feeding Rate (% body weight/day)		1.2	
Daily Feed Ration (kg)		12.0	
Fresh Water Intensity (kg/Lps)	130.5	266.9	403.2
Average Flow Rate (Lps)	7.6	3.7	2.5
TSS Prod'n @ 300 g/kg Feed (kg)	3.59	3.59	3.59
Projected Avg. Daily [TSS] (mg/L)	5.44	11.12	16.80
Observed [TSS] (mg/L)	4.73	11.15	17.56
TP Prod'n @ 7.6 g/kg Feed (kg)	0.091	0.091	0.091
Projected Avg. Daily [TP] (mg/L)	0.138	0.282	0.426
Observed [TP] (mg/L)	0.039	0.158	0.277
DP Prod'n @ 2.2 g/kg Feed (kg)	0.026	0.026	0.026
Projected Avg. Daily [DP] (mg/L)	0.040	0.082	0.123
Observed [DP] (mg/L)	0.012	0.032	0.052

Exhibit 6.3:
Efficiency of solids sedimentation for removal of settleable solids (SS), total suspended solids (TSS), and total phosphorus (TP) from intensive trout culture effluent.

Site	Design Overflow Rate ($m^3/m^2/d$)	% Removal SS	TSS	TP	Source
Lamar NFH	120.0	90.0	na	na	McLaughlin 1981
Jordan River NFH	58.7	79.2	65.8	na	"
Jones Hole NFH	57.5	91.2	90.0	na	"
Oswayo FCS	69.7	97.8	87.3	65.6	Mudrak 1981
Tionesta FCS	40.5	99.1	88.9	68.2	"
Big Spring FCS	21.4	99.0	88.0	76.7	"

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Exhibit 6.4:
Projected performance of settling basins at intensive rainbow trout culture operations in Ontario at three different overflow rates and assuming "very good" basin design.

DESIGN PARAMETERS

Scale-up Factor[1]	Design Overflow Rate[2] $m^3/m^2/d$	cm/s	Performance Overflow Rate[3] $m^3/m^2/d$	cm/s
2.2	43.2	0.050	95.0	0.110
2.2	64.8	0.075	142.6	0.165
2.2	86.4	0.100	190.1	0.220

PERFORMANCE PARAMETERS - STANDARD RACEWAYS

Untreated Effluent[4] mgTSS/L	mgTP/L	Design Overflow Rate $m^3/m^2/d$	cm/s	% Removal TSS	TP	Effluent Conc'n mgTSS/L	mgTP/L
8.43	0.214	43.2	0.050	89.5	70.3	0.89	0.064
8.43	0.214	64.8	0.075	85.5	67.0	1.22	0.071
8.43	0.214	86.4	0.100	81.5	63.6	1.56	0.078

PERFORMANCE PARAMETERS - OVAL RACEWAYS

Untreated Effluent[4] mgTSS/L	mgTP/L	Design Overflow Rate $m^3/m^2/d$	cm/s	% Removal TSS	TP	Effluent Conc'n mgTSS/L	mgTP/L
15.50	0.393	43.2	0.050	84.5	66.1	2.40	0.133
15.50	0.393	64.8	0.075	78.5	61.1	3.33	0.153
15.50	0.393	86.4	0.100	73.5	56.9	4.11	0.169

PERFORMANCE PARAMETERS - CIRCULAR TANKS

Untreated Effluent[4] mgTSS/L	mgTP/L	Design Overflow Rate $m^3/m^2/d$	cm/s	% Removal TSS	TP	Effluent Conc'n mgTSS/L	mgTP/L
11.12	0.282	43.2	0.050	87.5	68.6	1.39	0.089
11.12	0.282	64.8	0.075	83.0	64.9	1.89	0.099
11.12	0.282	86.4	0.100	79.0	61.5	2.34	0.109

1 Scale-up Factor = 2.2; i.e. theoretical removal efficiency of approx. 85% in basins with "very good" design (see Exhibit 3.4).
2 Design Vo based on hydraulic load and required surface area.
3 Performance Vo based on scaling factor turbulence adjustment (see Exhibit 6.1).
4 Projected values (see Exhibit 6.2).

It is evident that the effluent concentration of total phosphorus is the limiting factor governing the necessary level of efficiency for aquaculture wastewater treatment facilities. Over the range of design overflow rates examined in Exhibit 6.4 (i.e. 43.2 to 86.4 $m^3/m^2/d$), an average standard raceway, oval raceway, or circular tank operation will meet the 10 mg/L discharge criterion for TSS. Over this same range of overflow rates, however, only standard raceway operations will achieve the 0.10 mg/L non-compliance limit for total phosphorus discharge. In fact, an average standard raceway operation will achieve compliance limits at design overflow rates as high as 167 $m^3/m^2/d$ (0.193 cm/s), producing daily average discharge concentrations of TSS and TP equal to 2.6 and 0.100 mg/L, respectively. Circular tank operations reach a ceiling at a design overflow rate of approximately 65 $m^3/m^2/d$, producing a daily average discharge concentration equal to 0.099 mgTP/L.

Oval raceway facilities, once again, produce the poorest quality effluent and, therefore, require comparatively larger treatment facilities. The data presented in Exhibit 6.4 suggest that an average oval raceway operation will not produce a final effluent within compliance limits for TP at design overflow rates as low as 43.2 $m^3/m^2/d$ (0.05 cm/s). However, if one considers the <u>observed</u> concentrations of TP in untreated effluent at oval raceway operations and, furthermore, if the single largest observation is removed from the data set, the mean concentration of TP in oval raceway effluent falls to 0.279 mg/L. Assuming that this is representative of oval raceway operations, 64.2% of the TP must be removed to achieve the compliance limit. This requires that 82.2% of the TSS be removed, which corresponds to a design overflow rate of 49.3 $m^3/m^2/d$ (0.057 cm/s).

In view of these findings, design overflow rates below 167 $m^3/m^2/d$ (0.193 cm/s) are recommended for standard raceway operations and 64.8 $m^3/m^2/d$ (0.075 cm/s) for circular tank fish culture operations. This value should be reduced to 40.0 $m^3/m^2/d$ (0.046 cm/s) for oval raceway production units. At these rates, the effluent concentration of total phosphorus is projected to be marginally below the non-compliance limit of 0.10 mgTP/L. These data are presented in the following table, along with conventional flow and area terminology for ease of implementation. Note that these data assume the use of groundwater and/or springwater sources having a negligible influent concentration of total phosphorus. The maximum design overflow rates for fish farms utilizing surface waters will be much greater, ultimately depending upon the background concentration of total phosphorus.

Culture System	Design Vo ($m^3/m^2/d$)	Settling Rate (cm/s)	Req'd Area (ft^2/IGPM)
Standard Raceway	167	0.193	0.42
Oval Raceway	40	0.046	1.76
Circular Tank	65	0.075	1.08

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Since these values represent industry-wide recommendations for average facilities, specific overflow rates may necessitate fine tuning at individual aquaculture facilities to maximize performance. Routine water quality assessment for TSS and TP will be required to permit treatment unit adjustment. In all cases, to achieve optimum performance, it is imperative to compensate for inlet and outlet structure effects by increasing the length of the settling basin as required, over and above the area requirement defined by hydraulic loading and overflow rate. Refer to Section 6.2 for additional length requirements for specific settling basin designs.

6.5 Management Strategies for Effective Effluent Quality Control

Management strategies must address the issue of fish farms as sources of aquatic pollution on four principal fronts: feed and feeding practices, rearing unit design, solids settling unit design, and solids removal and disposal. All four of these factors are necessarily inter-related. A chain is only as strong as its weakest link and, therefore, pollution must be challenged on all fronts if abatement is to be effective.

6.5.1 Feed and Feeding Practices

Feed is ultimately the source of pollution in aquaculture. From the feed manufacturers' perspective, R&D efforts must be focused upon the development of commercial feeds which have reduced phosphorus content and higher digestibility. Indeed, on-going research in these areas at nearly every major feed manufacturer and fish nutrition laboratory in North America, Europe and Japan is steadily improving the overall quality of feed.

It is too convenient, however, to blame feed manufacturers for feed-related pollution. The fish culturist can make considerable inroads toward reducing the pollution impact of feeds through the use of wise feeding practices. Moreover, such practices often also produce a financial benefit. Rough handling and improper storage of feeds promote pellet erosion, resulting in an increased level of fines which cannot be utilized by the fish. Proper storage and handling, therefore, can reduce the pollution impact of feeds and result in less feed wastage. Prior to adding feeds to feed hoppers or troughs, screening the pellets will remove the fines, thus preventing their addition to the water. Feeding practices can also be managed to reduce pollution and improve fish production. A carefully monitored feeding program will enable the fish culturist to select the optimum pellet size for the size of fish in the facility. Feeding of oversized and/or undersized pellets promotes waste, inefficiency due to poorer feed conversion, and pollution. Educational symposia on feeding strategies and programs, sponsored by feed manufacturers and/or university extension offices, would be highly beneficial.

6.5.2 Rearing Unit Design

The results of this study clearly indicate that different designs of fish production facilities have different pollution impact. Selection of those designs which facilitate solids removal and minimize the release of particulate and soluble pollutants should be emphasized in the development of new aquaculture ventures.

In all culture facilities, tank design should facilitate the rapid and gentle removal of waste feed and particulate fecal matter from the water column. The longer these materials remain in suspension, the more they are subject to agitation and, consequently, the smaller they become. These smaller particles are then more difficult to remove from suspension and require substantially larger treatment units to achieve the desired level of efficacy. Additionally, leaching of soluble nutrients is enhanced as particle size decreases.

When designing and constructing culture tanks, it should be borne in mind that production area does not limit the amount of fish that can be produced; the volumetric flow of water does. In Ontario, a standing crop of 245.8 $\pm$ 226.1 kg fish per Lps of water (41.1 $\pm$ 37.7 lbs/IGPM) has been observed as an industry-wide average production intensity. This average intensity is not different between the three main groups of fish culture operations examined. The production area of these groups averages 242.8 $\pm$ 358.6 m^2. Moreover, average area is significantly different between the three principal designs (Exhibit 4.5). Clearly then, some culture units are larger than they need be.

Given a constant water flow rate and tank depth, increased area means that the rate of water movement through the tank is reduced, and slower flow results in more solids settling within the rearing unit where it is not desired. Solids settling within the culture unit hinders solids removal and, hence, increases the solubilization of nutrients. Shallow tanks (generally less than 76 cm or 30" of water) are recommended to provide good horizontal flow and to promote self-cleaning. In shallower tanks, fish density is higher and thus fish activity, coupled with aeration, generally keeps particulate matter suspended within the water column so that it is carried to the settling unit.

Many existing aquaculture operations can improve solids removal from the culture units by reducing the level of water in the units. In fact, at one highly-intensive facility in the province, the shallowing of raceways from 152 cm to 76 cm greatly reduced solids accumulation in the production unit and facilitated daily maintenance procedures, with no reduction in productivity. Standard raceway and circular tank culture systems should be selected in future design considerations due to the quality of discharged effluent observed at these facilities.

6.5.3 Solids Settling Unit Design

The specific requirements for effective solids settling unit design are presented on a micro level in Section 6.2 and will not be repeated here. From a macro level, however, one key issue warrants discussion; that of treatment unit size. In virtually all applications, a number of small treatment units designed

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to treat a portion of the total process flow is recommended, as opposed to one large treatment unit sized to treat the entire process flow. Small units, such as in-raceway settling basins, are easier to manage and clean. It is more realistic to schedule cleaning of ten smaller basins, say 15 m^2 each, than one large basin that is 150 m^2. In each case, the total settling area is the same, however, cleaning of one small basin as part of a daily routine can be scheduled more readily than can cleaning the entire large basin. Hence, the smaller units are more manageable.

6.5.4 Solids Removal and Disposal

Sedimentation of solid matter from fish culture effluent is only the first step of the effluent treatment process. Once settled to the floor of the settling basin, the accumulated manure must be effectively removed and disposed.

Solids Removal. Vacuuming of settled manure, much the same way that swimming pools are vacuumed, still offers the best method for solids removal. Vacuum heads designed specifically for fish culture are commercially available, or can be easily home-made.

The frequency of vacuuming must also be addressed since, over time, accumulated solids may become anaerobic at lower layers, resulting in the release of dissolved nutrients. Moreover, Mudrak (1981) reports that aged manure becomes quite viscous and removal is impaired. Before either of these events occur, however, the depth of the manure will certainly increase to a point where basin efficiency is greatly reduced due to lost volume.

Aerobic solubilization of dissolved nutrients (especially phosphorus) is most rapid during the first 2 to 3 days after the solid pellet is discharged into the water, and comparatively little aerobic solubilization occurs beyond day 4 (Zeigler 1988; Parjala 1984). Consequently, unless the solids had been vacuumed from the settling basins and production facilities within 2 to 3 days prior to site visits, the data collected during this investigation represent steady-state concentrations of dissolved and total phosphorus. As such, so long as effluent compliance criteria are achieved in treated wastewaters, the frequency of solids removal from settling facilities is somewhat flexible. From the fish culturists' perspective, relatively frequent cleaning (1-2 week intervals) is easiest since the depth of accumulated manure remains manageable within this time period. Mudrak (1981) suggests a maximum of six weeks between cleanings, however, an interval not longer than two weeks will facilitate removal and should effectively maintain appropriate effluent quality.

Solids Disposal. There is a Chinese philosophy which states: "substances that by others may be considered wastes are only resources out of place." Such is the case with settled fish manure, which has similar properties to low grade fertilizer. Typical nutrient concentrations in trout culture manure are presented in the following table.

Nutrient Composition of Settled Manure (% dry weight)		
	Mudrak & Stark	Willet & Jakobsen
Nitrogen	1.4% to 4.9%	3.30%
Phosphorus	1.5% to 3.0%	1.03%
Potassium	0.2% to 0.7%	0.03%
Organic Carbon	NA	25%
pH	NA	6.31

Consequently, land application of fish manure remains the best solution for disposal. Since the manure is highly liquid (generally less than 5% solids), it can be spread directly onto agricultural land using liquid manure spreaders and/or irrigation pumps. Naturally, this solution is only feasible during the agricultural growing season. Throughout the winter months, it is necessary to store the vacuumed manure in a suitable holding facility.

The application of settled fish culture wastes over agricultural land has been successfully demonstrated. While heavy manure loadings can be detrimental to cover crops and can cause severe odour problems, properly managed loadings can be beneficial to vegetative growth. Trout manure has been found to increase the availability and uptake of both nitrogen and phosphorus, and enhances the dry matter yield of crop harvests. No significant increases in the concentration of potassium (K), sulphur (S), magnesium (Mg), copper (Cu), zinc (Zn), aluminum (Al), boron (B), iron (Fe), sodium (Na), calcium (Ca), cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni), or molybdenum (Mo) were detected in cover crops (Mudrak and Stark 1981; Willet and Jakobsen 1986).

The concentration of nitrogen in settled trout manure is the limiting factor governing land application rates. Pennsylvania experience has shown that, in general, manure can be safely applied over agricultural land. For mixed grass crops, which have a nitrogen uptake capacity of about 224 kg/ha (200 lbs/Ac), manure application rates should approximate 120 m^3 per hectare (10,600 Imp. gal/Ac), assuming a 5% solids concentration.

6.6 Economics of Effluent Treatment

Internationally, aquaculture tends to be most profitable in regions where environmental regulatory controls are lax or non-existent (Pruder 1989). While any recommendations put forth in this study must necessarily be effective in controlling effluent concentrations of suspended solids and phosphorus, the installation and operation of any wastewater treatment facility must be economically feasible for the industry to adopt. Effluent treatment does not increase productivity and, therefore, the expense associated with effluent treatment must be minimized. Consequently, least-cost treatment technologies, based upon effectiveness, simplicity and practicality, must be applied. From a

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cost/benefit perspective, Parjala (1984) reports that sedimentation technologies present the most realistic methodology for clarifying aquaculture effluents.

Within the context of aquaculture in Ontario, Stechey and Kantor (1988) examined the underlying cost structure of intensive trout farming. These data, which are similar to cost structure data for intensive trout culture presented by Lewis (1979) and Castledine (1986), have been used as the basis for this economic assessment. Note, however, that this analysis is not intended to be a comprehensive assessment of the economics of trout culture. Rather, it is presented to offer comparative assessment of practical effluent treatment operations for standard raceway, oval raceway, and circular tank production facilities.

The following assumptions have been made in conjunction with this economic study.

1) Analyses have been conducted for 3 hypothetical farms, each having an annual production capacity of 45,000 kg (100,000 lbs). One farm has standard raceways, one has oval raceways, and the third has circular tanks. The average standing crop at these operations equals one-third of the annual production output (15,000 kg).

2) Water flow for each facility is calculated using the observed production intensities for the three classes of farms (see Exhibit 4.5). The number and size of rearing units is calculated accordingly.

3) Moccia and Bevan (1989) indicate that the average farm gate price received by farmers in 1988 was $5.06/kg whole fish. Dupont (1990) suggests that current figures reflect a reduction in the farm gate price to approximately $4.41/kg whole fish ($2.00/lb). This latter price is used in the analysis.

4) In all cases, it has been assumed that the farm is already in production and that effluent treatment facilities are to be retrofitted into the facility. The most appropriate design has been selected for each operation.

The rationale applied to reliably forecast productivity, culture system and effluent treatment design, manure storage requirements, and the general necessities of the treatment facility are presented in Exhibit 6.5. For the standard raceway operation, in-raceway settling is most appropriate. In standard raceways, it is necessary to design the treatment units such that they are capable of handling the entire process flow through each raceway, including any water reuse. External circular clarifiers are most appropriate for oval and circular tank operations. With circular production tanks, the opportunity does not exist to treat the effluent within the culture tank and, therefore, treatment must be in a separate basin. Note, however, that two smaller units are used rather than one large unit. Due to the substantial volume of reuse water in oval raceway operations, it is more practical to treat only the discharged effluent (equivalent to the influent flow) in external basins rather than treating the entire process flow with in-raceway settling zones. Again, two units are used.

The requirements for inlets and outlets, a vacuuming system, labour, electricity, and water quality sampling are also described in Exhibit 6.5.

In Exhibit 6.6, a dollar figure has been affixed to each component of effluent treatment. These have been broken down into fixed (capital) costs and variable (operating) costs to facilitate the analysis. A 10 year straight-line depreciation schedule has been applied on capital expenditures to derive an annual expense. The total annual operating expense is lowest for effluent treatment in circular tank production facilities ($3583). Treatment operations are marginally more expensive in standard raceway operations ($3897/yr), and most expensive in oval raceway facilities ($4392/yr). The largest component of the total expense is the annual operating cost, which is approximately three times greater than the amortized portion of the total fixed cost (Exhibit 6.6).

For the hypothetical intensive trout culture operations, gross revenue has been projected at $198,450; i.e. 45,000 kg @ $4.41/kg. All variable and fixed costs have been allocated based upon the expenses allocated to each account, as presented by Stechey and Kantor (1988). Without effluent treatment, earnings before interest, tax, and depreciation (EBIT) are projected at 21.5% of sales. Variable and fixed costs account for 71.5% and 28.5% of total costs, respectively (Exhibit 6.7).

As expected, incorporation of effluent treatment causes the bottom line to worsen in all three production facilities. From a cost perspective, effluent treatment accounts for 2.25% to 2.74% of total production costs. Comparatively, UMA Engineering (1988) estimates effluent treatment costs between 5% and 10% of total production costs. Furthermore, the UMA study presents data which suggest an increase in production costs ranging from $0.07 to $1.74 per kilogram of fish produced. This analysis indicates that, on a per kilogram basis, effluent treatment will increase total production costs by $0.08 in circular tank production operations, $0.09 in standard raceway operations, and $0.10 in oval raceway facilities. Total production costs increase from $3.46/kg to more than $3.54/kg. Consequently, profit margins decline by approximately $0.08 to $0.10 per kilogram ($0.036 to $0.045 per lb) (Exhibit 6.7).

Note, however, that these data reflect projected treatment costs in a very large commercial operation. In Ontario, many fish farms are small ventures which serve to supplement the income of traditional farmers. Moreover, since the annual operating cost of effluent treatment presents the largest cost component of effluent treatment, and since these will change little with the size of the facility (water quality monitoring costs will not change), then the costs become much more significant in smaller-scale operations.

Exhibit 6.5:
Rationale for economic analysis of effluent treatment operations in intensive salmonid aquaculture.

	Standard Raceways	Oval Raceways	Circular Tanks
PRODUCTIVITY			
Annual Production (kg)	45,000	45,000	45,000
Stdg. Crop (1/3 Prod'n)	15,000	15,000	15,000
Intensity (kg/Lps)[1]	198.7	125.3	266.9
Hydraulic Flow Rate (Lps)	75.5	119.7	56.2
CULTURE SYSTEM			
Rearing Unit Dimensions	30.5x2.4x0.76	61.0x4.8x0.76	5.8 dia. x 0.76
No. of Units	8	2	15
Unit Flow Rate (Lps/IGPM)	9.4/125	119.7/1580	3.7/49
EFFLUENT TREATMENT			
Design	In-raceway	Ext. Circular	Ext. Circular
No. of Units	8	2	2
Hydr. Load/Unit (m^3/d)	812	1741	1457
Design Vo (m^3/m^2/d)	86.4	49.2	64.8
Unit Dimensions	5.75x2.44x0.76	7.3 dia. x 0.76	5.8 dia. x 0.76
MANURE STORAGE LAGOON			
Volume (0.864m^3/dx150 d)	129.6	129.6	129.6
REQUIREMENTS			
Structure	N/R	2 tanks 15m^3 conc. pad	2 tanks 10m^3 conc. pad
Inlet	15m^2 screen 57m framing	30 m 25cm pipe 2 baffles	30 m 15cm pipe 2 baffles
Outlet	176m damboards	46m 10cm Big O	37 m 10cm Big O
Vacuum Pump	1 HP	1 HP	1 HP
Vacuum Head & Hose	1 ea	1 ea	1 ea
Discharge Pipe	45 m	45 m	45 m
Labour (vacuuming)	4 hrs/wk	4 hrs/wk	3 hrs/wk
Electrical	3 kwh/wk	3 kwh/wk	2.2 kwh/wk
Sampling (source/effl.)	2-TP 2-TSS/mo	2-TP 2-TSS/mo	2-TP 2-TSS/mo

[1] For standard raceways, total water use is considered since treatment is in-raceway; for ovals and circulars, treatment volumes equal the flow of source water, net of reuse, since treatment is external to fish culture.

Exhibit 6.6:
Annual capital and operating expenses for effluent treatment facilities incorporated into existing intensive salmonid aquaculture operations.

	Standard Raceways ($)	Oval Raceways ($)	Circular Tanks ($)
CAPITAL COSTS			
STRUCTURE[1]			
Tanks	N/R	1750	1300
Concrete ($130/m^3)	N/R	1950	1300
Preparation	N/R	400	300
INLET			
Screens	250	N/R	N/R
Frames	70	N/R	N/R
Piping	N/R	1100	700
Baffles	N/R	50	50
OUTLET			
Damboards	600	N/R	N/R
Big O Pipe	N/R	70	55
Piping	N/R	550	350
VACUUM SYSTEM			
Pump	200	200	200
Vac. Head	100	100	100
Discharge Pipe	140	140	140
MANURE STORAGE LAGOON			
Excavation	2600	2600	2600
Fencing	1740	1740	1740
TOTAL CAPITAL COST	5700	10650	8835
ANNUAL FIXED EXPENSE[2]	570	1065	884
OPERATING COSTS			
LABOUR (@ $12/hr)	2496	2496	1872
LABORATORY ANALYSES 2-TP, 2-TSS per mo. + deliv.	816	816	816
ELECTRICITY @ $.073/kwh	15	15	11
ANNUAL OPERATING EXPENSE	3327	3327	2699
TOTAL ANNUAL EXPENSE	3897	4392	3583

[1] Fish culturists will install treatment units themselves.
[2] 10 yr. depreciation schedule.

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Exhibit 6.7:
Economic projections reflecting the cost of effluent treatment in standard raceway, oval raceway, and circular tank salmonid aquaculture operations. In-raceway settling is applied in standard raceways, and external circular clarifiers are applied for oval raceway and circular tank culture facilities.

INDUSTRY AVERAGE COST STRUCTURE - NO EFFLUENT TREATMENT

Production (kg)		45,000		
Farm Gate Price ($/kg)		4.41		
	% Revenue	$	% Costs	$/kg
REVENUE	100.00	198,450		4.41
EXPENSES				
Variable Costs				
Feed	28.23	56,014	35.96	1.24
Eggs/Fingerlings	5.67	11,248	7.22	0.25
Mortality	0.81	1,617	1.04	0.04
Chemicals/Drugs	0.45	888	0.57	0.02
Farm Supplies	0.79	1,571	1.01	0.03
Labour	15.64	31,036	19.92	0.69
Transportation	4.35	8,630	5.54	0.19
Other Expense	0.16	319	0.20	0.01
Effluent Treatment	0.00	0	0.00	0.00
Total Var. Costs	56.10	111,323	71.47	2.47
Contribution Margin / %		87,127		1.94
Fixed Costs				
Insurance	2.11	4,190	2.69	0.09
Repairs & Maint.	5.16	10,247	6.58	0.23
Utilities	6.90	13,685	8.79	0.30
Office Supplies	1.25	2,482	1.59	0.06
Prof. Fees	6.98	13,844	8.89	0.31
Effluent Treatment	0.00	0	0.00	0.00
Total Fixed Costs	22.40	44,447	28.53	0.99
Total Costs	78.49	155,770	100.00	3.46
EBIT* / % Profit Margin	21.51	42,679		0.95

* Earnings Before Interest, Tax, & Depreciation

STANDARD RACEWAY EFFLUENT TREATMENT COST STRUCTURE

Production (kg)		45,000		
Farm Gate Price ($/kg)		4.41		
	% Revenue	$	% Costs	$/kg
REVENUE	100.00	198,450	N/A	4.41
EXPENSES				
Variable Costs				
Feed	28.23	56,014	35.08	1.24
Eggs/Fingerlings	5.67	11,248	7.04	0.25
Mortality	0.81	1,617	1.01	0.04
Chemicals/Drugs	0.45	888	0.56	0.02
Farm Supplies	0.79	1,571	0.98	0.03
Labour	15.64	31,036	19.44	0.69
Transportation	4.35	8,630	5.40	0.19
Other Expense	0.16	319	0.20	0.01
Effluent Treatment	1.68	3327	2.08	0.07
Total Var. Costs	57.77	114,650	71.81	2.55
Contribution Margin / %		83,800		2.51
Fixed Costs				
Insurance	2.11	4,190	2.62	0.09
Repairs & Maint.	5.16	10,247	6.42	0.23
Utilities	6.90	13,685	8.57	0.30
Office Supplies	1.25	2,482	1.55	0.06
Prof. Fees	6.98	13,844	8.67	0.31
Effluent Treatment	0.29	570	0.36	0.01
Total Fixed Costs	22.68	45,018	28.19	1.00
Total Costs	80.46	159,668	100.00	3.55
EBIT* / % Profit Margin	19.54	38,782		0.86
EFFLUENT TREATMENT COST	1.96	3897	2.44	0.09

Exhibit 6.7: (cont'd)
Economic projections reflecting the cost of effluent treatment in standard raceway, oval raceway, and circular tank salmonid aquaculture operations. In-raceway settling is applied in standard raceways, and external circular clarifiers are applied for oval raceway and circular tank culture facilities.

OVAL RACEWAY EFFLUENT TREATMENT COST STRUCTURE

Production (kg)		45,000		
Farm Gate Price ($/kg)		4.41		
	% Revenue	$	% Costs	$/kg
REVENUE	100.00	198,450	N/A	4.41
EXPENSES				
Variable Costs				
Feed	28.23	56,014	34.97	1.24
Eggs/Fingerlings	5.67	11,248	7.02	0.25
Mortality	0.81	1,617	1.01	0.04
Chemicals/Drugs	0.45	888	0.55	0.02
Farm Supplies	0.79	1,571	0.98	0.03
Labour	15.64	31,036	19.38	0.69
Transportation	4.35	8,630	5.39	0.19
Other Expense	0.16	319	0.20	0.01
Effluent Treatment	1.68	3327	2.08	0.07
Total Var. Costs	57.77	114,650	71.58	2.55
Contribution Margin / %		83,800		1.86
Fixed Costs				
Insurance	2.11	4,190	2.62	0.09
Repairs & Maint.	5.16	10,247	6.40	0.23
Utilities	6.90	13,685	8.54	0.30
Office Supplies	1.25	2,482	1.55	0.06
Prof. Fees	6.98	13,844	8.64	0.31
Effluent Treatment	0.54	1065	0.66	0.02
Total Fixed Costs	22.93	45,513	28.42	1.01
Total Costs	80.71	160,163	100.00	3.56
EBIT* / % Profit Margin	19.29	38,287		0.85
EFFLUENT TREATMENT COST	2.21	4392	2.74	0.10

CIRCULAR TANK EFFLUENT TREATMENT COST STRUCTURE

Production (kg)		45,000		
Farm Gate Price ($/kg)		4.41		
	% Revenue	$	% Costs	$/kg
REVENUE	100.00	198,450	N/A	4.41
EXPENSES				
Variable Costs				
Feed	28.23	56,014	35.15	1.24
Eggs/Fingerlings	5.67	11,248	7.06	0.25
Mortality	0.81	1,617	1.01	0.04
Chemicals/Drugs	0.45	888	0.56	0.02
Farm Supplies	0.79	1,571	0.99	0.03
Labour	15.64	31,036	19.48	0.69
Transportation	4.35	8,630	5.42	0.19
Other Expense	0.16	319	0.20	0.01
Effluent Treatment	1.36	2699	1.69	0.06
Total Var. Costs	57.46	114,022	71.55	2.53
Contribution Margin / %		84,428		1.88
Fixed Costs				
Insurance	2.11	4,190	2.63	0.09
Repairs & Maint.	5.16	10,247	6.43	0.23
Utilities	6.90	13,685	8.59	0.30
Office Supplies	1.25	2,482	1.56	0.06
Prof. Fees	6.98	13,844	8.69	0.31
Effluent Treatment	0.45	884	0.55	0.02
Total Fixed Costs	22.84	45,332	28.45	1.01
Total Costs	80.30	159,354	100.00	3.54
EBIT* / % Profit Margin	19.70	39,096		0.87
EFFLUENT TREATMENT COST	1.81	3583	2.25	0.08

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7.0 INTERIM GUIDELINES & THE CERTIFICATE OF APPROVAL

In Ontario, the Municipal Industrial Strategy for Abatement (MISA) presents a significant effort directed toward the reduction of water pollution from all municipal and industrial users of water. This initiative presents a conscientious policy targeted at restricting the concentration of pollutants in discharged effluents in a manner which is in line with the implementation of BATEA (see below). As technologies improve, the restrictions will become tighter.

The two principal bases for abatement are (1) the best available pollution control technology which is economically achievable (BATEA) and, (2) the impact of the discharged pollutant(s) on the receiving body of water. In some cases, the latter may be more restrictive than the former due to the inability of the receiver to assimilate the pollution load. Although MISA is being implemented on a sector-by-sector basis, and in spite of the fact that there is no sector classification for aquaculture, the underlying philosophy of MISA is currently being adopted in all industrial and municipal sectors. In aquaculture, BATEA is generally applied, however, in some regions, where receiving bodies consist of pristine streams and rivers, the more restrictive water quality track may be applied.

By the power and authority granted under the Ontario Water Resources Act, the Ontario Ministry of the Environment has established guidelines (see Appendix V) for the design, operation, and management of fish culture operations in the province. Within the context of returning process water to receiving streams, these guidelines dictate that fish farmers must:

1) treat all process water, to a level of cleanliness as stated by the Ministry, prior to discharge;

2) provide for appropriate storage and disposal of collected fish manure;

3) collect and submit regular (monthly) samples of influent and effluent water for TSS and TP analysis;

4) maintain a log of daily operations at the farm; and,

5) report the findings of the water quality analyses and the data log to the Ministry on a monthly and annual basis.

The Ministry has taken the position that efficient and effective solids management is to be the focus of these guidelines. By reducing the concentration of total suspended solids in fish farm effluent, concentrations of other pollutants (namely total phosphorus, BOD, TKN) are also reduced. Moreover, solids management is perhaps the only aspect of effluent quality control which is realistically achievable in intensive salmonid aquaculture.

Current guidelines indicate that treatment facilities at fish culture operations be designed, constructed, and operated with the intention of routinely producing an effluent stream having a maximum concentration of 5 mg TSS/L above the background level of TSS in the source water. An absolute maximum

concentration of 0.05 mg TP/L has been established for design purposes, however, at sites using a surface water supply where background concentrations of TP are greater than 0.05 mg/L, design criteria require that no increase over background levels be incurred.

The operator(s) of a fish culture facility will be considered to be in non-compliance with Ministry guidelines on any occasion when the concentration of TSS in the final farm discharge is observed to be greater than 10 mg/L above the concentration of TSS in the source water. Similarly, at no time can the concentration of TP in the final farm effluent exceed 0.10 mg TP/L. Notwithstanding this, at sites using surface water where the source water concentration of TP exceeds 0.10 mg/L, farm effluent concentrations of TP cannot exceed background levels.

These phosphorus discharge criteria may be severely limiting to future and existing fish culture operations in the province. The requirement that effluent concentrations of TP not exceed source water concentrations implies that removal of total phosphorus from discharged culture water must be 100% efficient at those culture sites where the source water already contains total phosphorus concentrations greater than 0.05 mg/L. Since this is impossible, such fish culture operations would be in non-compliance with Ministry regulations. The only recourse for aquaculturists remains to undertake a study to demonstrate the assimilative capacity of the receiving water course and the impact of the fish culture operation.

The requirement for a manure storage lagoon (Sections 2.6 and 3.1)[3] for retention during the winter is not contested. This structure, however, need not be lined in all cases. Certainly, at sites containing highly porous soils, or where the ground structure is unable to retain the vacuumed manure, a lined pond is required. Several sites have soils of sufficiently low permeability that the expense of a lined pond can be eliminated. Moreover, the manure itself serves to seal pond bottoms. Consequently, the necessity for a lined pond should be assessed on a site-specific basis.

On the same subject, research is required to assess the impact of overflow drains from manure storage lagoons, which feed into subsurface absorption fields. Such drainage facilities would greatly reduce the size and expense associated with manure storage by permitting clarified supernatant to be removed from the lagoon and may thus enhance fish farmer participation in effluent quality control programs.

The requirement for routine sampling of influent and effluent process water (Sections 2.7 & 3.3) raises considerable concern on two fronts: costs and usefulness of data. The Ministry's viewpoint is that economics must be considered in any business venture and that water quality monitoring is only a portion of the overall cost structure of commercial fish production. While this is true, the specific case of commercial aquaculture must be considered. In Ontario, the aquaculture industry remains fragmented, with 25% of commercial operations producing less than 2,000 kilograms of fish per year (Moccia and Bevan

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[3] Sections of the Interim Guidelines (see Appendix V).

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1989). Consequently, the financial burden of monthly effluent monitoring will be significant on these smaller producers. For example, sampling costs of $816 for an operation producing only 2000 kg of fish account for 9.25% of total operating revenue as opposed to only 0.4% of income for the large-scale producer.

Furthermore, the purpose of collecting water quality samples is to compile data on fish culture operations and to monitor effluent quality. Since the responsibility of collecting the samples lies with the aquaculturist, considerable variability will be introduced into the resultant data set. Consequently, to be effective, an OME-directed or a co-operative monitoring program will be required. This may entail a shared-cost approach and the education of aquaculturists with respect to proper sampling procedures.

In concurrence with the UMA Engineering report (1988), the maintenance of a daily record of weather events, power outages, etc. (Section 2.8) will likely offer little to the interpretation of effluent quality data. It will, however, impact upon the aquaculturists' perception of enforced effluent treatment, likely creating greater discontent and reducing co-operative participation. Instead, only routine fish culture records of feeding rates, fish transfers, etc., which are more related to effluent quality, should be maintained.

On an annual basis, each aquaculture operator is required to submit a report to the District Officer which summarizes all sample results, log entries, and abatement procedures at the operation (Section 2.9). It is likely, however, that these reports will be of little use to Ministry personnel since, in many instances, fish farmers are not skilled in the interpretation of water quality results. Moreover, given the same data, ten aquaculturists will likely provide ten distinct interpretations. Such reports will lack the consistency and validity required to make them beneficial. Consequently, on an annual basis, the Ministry should consider in-house interpretation and reporting of monthly log records submitted by individual aquaculturists or, alternatively, funds should be allocated to contract this task to outside organizations. The task of interpreting and reporting annual effluent quality records should not be delegated to aquaculturists. To facilitate the information gathering process, the Ministry should consider compiling and distributing standard "reporting sheets" which direct the aquaculturist to provide specific information.

Lastly, from a design and monitoring perspective, the Ministry's two-level approach (i.e. 5.0 ppm TSS for design and 10 ppm for monitoring and enforcement) appears appropriate. Upon identification of a farm which does not meet the established compliance standards, every effort should be made to determine the cause of non-compliance. Sufficient direction is provided within this report to enable Ministry personnel to assess the design and operation of production and effluent treatment facilities and make constructive recommendations. Foremost, every effort should be made to control the effluent concentration of total suspended solids, since this remains the only practical course for effluent quality control in commercial aquaculture. At the farm level, phosphorus control can only be practically achieved via effective solids control. The specific design and non-compliance limits for total suspended solids and total phosphorus should be carefully considered by the Ministry's Aquaculture Committee. The information provided in Section 6.4 (especially Exhibits 6.2 through 6.4) will facilitate the Committee's task.

8.0 PROJECT SUMMARY

8.1 Ontario Aquaculture Operations

8.1.1 The three principal commercial fish culture facility designs utilized in Ontario have been found to produce more or less the same amount of fish per unit water flow through the system.

8.1.2 Generally, standard raceways and circular tanks are similar with respect to production parameters and effluent quality. Oval raceways are distinctively different, producing poorer quality effluent; particularly, TP, DP, TKN, NH_3, and NO_2 have been observed to be discharged in greater concentrations.

8.1.3 In all three designs, individual production and management practices are not correlated with solids settling behaviour. Cumulative design curves of sedimentation behaviour are different on a group basis, however. Suspended particulate matter from oval raceway production facilities displays slower settling rates than particles from standard raceway and circular tank production facilities. The latter two groups are not statistically different.

8.1.4 Settling behaviour is discrete in all three facilities.

8.1.6 In all three groups, production intensity is positively correlated with enhanced concentrations of dissolved nutrients (TP, DP, NH_3, TKN) in the discharged effluent.

8.1.7 Feed-related factors (feed brand, feed type, feeding method) appear to be subordinate to facilities design and culture practices with respect to pollution impact.

8.2 Effluent Treatment Design

8.2.1 Overflow rate <u>must</u> be the basis for effective treatment facility design. Specific design parameters are laid out in Sections 6.2 and 6.3. In all cases, the required level of treatment efficiency will be governed by the effluent concentration of total phosphorus since solids criteria are generally easily attained, even at relatively high overflow rates. In many cases, phosphorus criteria will be difficult to meet on a continuous basis. To achieve compliance limits, the following overflow rates (in $m^3/m^2/d$) should be applied: Standard Raceways - 167; Oval Raceways - 40; Circular Tanks - 65. These values will provide average effluent concentrations of TSS considerably below the compliance limits; however, TP concentrations will approach or marginally exceed the 0.10 mg/L compliance limit. Further reduction of effluent phosphorus concentrations will likely be achieved only from improved feed formulations, which have a reduced phosphorus content (see Section 8.3).

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8.2.2 Generally, the use of several smaller treatment units, each designed to clarify a portion of the total system flow, is more appropriate than having one large treatment unit to clarify the entire system flow.

8.2.3 For maximum effectiveness, the design of effluent treatment operations should be conducted or approved by qualified personnel having an understanding of aquaculture operations and the related effluent characteristics and constraints.

8.3 Best Management Strategies

8.3.1 The development and commercialization of low-phosphorus feeds is required to facilitate the reduction of phosphorus from aquaculture operations. Many commercial feeds currently contain excess dietary phosphorus.

8.3.2 At the farm level, improved feed handling and storage, and feed screening to minimize the introduction of "fines" to the water column, will also reduce the pollution impact of commercial aquaculture. As well, properly managed feed programs can reduce feed waste and pollution by providing feeds of optimum pellet size to the fish.

8.3.3 Fish culture facilities should be designed to maximize fish production <u>and</u> promote the removal of solids wastes from the culture medium. To this end, shallow tanks (<76 cm) are recommended. Tank flows should be engineered to prevent solid waste accumulation in production zones, and to facilitate solids removal in settling zones. Moreover, standard raceway and/or circular tank facilities are most appropriate.

8.3.4 Vacuuming of settled manure from the bottom of clarifiers remains the most effective method for waste removal.

8.3.5 Due to the highly liquid state of settled fish manure and its low-grade fertilizer properties, application of settled manure on agricultural land remains the most appropriate method for disposal of solid wastes from fish culture.

8.3.6 Assuming that treatment facilities are retrofitted into existing fish culture operations, production costs can be expected to increase by approximately $0.08 to $0.10 per kilogram of fish produced. Total effluent treatment costs are greatest in oval raceway operations and lowest in circular tank operations.

8.4 Enforcement of Ministry Guidelines

8.4.1 If the current total phosphorus guidelines are enforced, it is likely that several farms will not achieved compliance limits due to the concentration of total phosphorus in their <u>source</u> water. As well, it should be noted that the best available technologies which are economically achievable (i.e. sedimentation and/or filtration) may not be sufficient to reduce phosphorus levels to compliance limits due to the solubility of phosphorus

in fish farming wastes and the excess concentrations of phosphorus in many commercial feeds.

8.4.2 Before the interim guidelines are finalized and enforced, more definitive research is required with respect to phosphorus loading from aquaculture operations.

8.4.3 Research is required relating to the discharge of clarified supernatant from manure storage lagoons into subsurface absorption fields.

8.4.4 The Ministry should meet with the membership of the Ontario Trout Farmers' Association to discuss the final draft of the interim guidelines prior to their implementation and enforcement. This will enable both parties to offer their concerns and it will promote industry-government co-operation. A co-operative effort will best protect the environment.

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APPENDIX I

Field Survey Questionnaire

CANADIAN
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AQUACULTURE WASTEWATER TREATMENT
DATA SHEET

Farm No: _____ Date: _____

Fish Farm: _____ Operator: _____

Address: _____ Species: _____

_____

OPERATIONS:

Annual Prod'n: Foodfish (lbs\kg) _____

Fingerlings (#) _____

Feed Brand: [] Martin's [] EWOS [] Other: _____

[] Floating [] Sinking

Water Source: [] Well(s) [] Spring(s) [] Surface

Volume (IGPM\LPM): _____ _____ _____

Water Flow: [] Pumped [] Gravity

SAMPLED UNIT:

[] Tanks Prod'n Area (ft\m): _____ Dia. _____ Deep

[] Raceways Prod'n Area (ft\m): _____ L _____ W _____ D

Carrying Capacity in unit (lbs\kg\# fish): _____

Approximate Size of Fish: (cm\in\lbs\g): _____

Feed Method: [] Demand [] Hand [] Automatic [] Other

Water Supply: Q (IGPM\LPM) _____ [] Flow-Thru

[] Re-use: _____% Temp (C\F): _____

EFFLUENT TREATMENT:

Method: [] In-Raceway Settling [] Ext. Settling [] Other

Dimensions: _____

Hydr. Load Rate: _____

Flow Pattern (IN/OUT): _____

Comments: _____

_____

MOE SAMPLE LOCATIONS:

Sample 1: _____ Sample 2: _____

Sample 3: _____ Sample 4: _____

APPENDIX II
Water Quality Data from Participating Fish Farms

FARM	GRP	INFLUENT (SOURCE)			PRODUCTION EFFLUENT			NET PROD'N EFFLUENT			FARM EFFLUENT			NET FARM EFFLUENT		
		[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]
26	1	2.31	0.015	0.066	6.26	0.046	0.022	3.95	0.031	-0.044	3.64	0.069	0.038	1.33	0.054	-0.028
1	1	NA	0.009	0.002	NA	0.126	0.074	NA	0.117	0.072	NA	0.137	0.080	NA	0.128	0.078
21	1	0.00	0.003	0.003	6.05	0.390	0.018	6.05	0.387	0.015	4.19	0.160	0.089	4.19	0.157	0.086
3	1	23.27	0.016	0.010	30.07	0.062	0.013	6.80	0.046	0.003	36.75	0.054	0.014	13.48	0.038	0.004
55	1	2.81	0.008	0.001	15.41	0.170	0.001	12.60	0.162	0.000	7.01	0.085	0.001	4.20	0.077	0.000
76	1	0.00	0.010	0.009	4.45	0.041	0.020	4.45	0.031	0.011	2.38	0.004	0.003	2.38	-0.006	-0.006
74B	1	2.47	0.008	0.003	4.49	0.055	0.009	2.02	0.047	0.006	4.49	0.055	0.009	2.02	0.047	0.006
43	1	9.03	0.051	0.009	13.43	0.305	0.063	4.40	0.254	0.054	14.85	0.210	0.063	5.82	0.159	0.054
8	1	2.78	0.005	0.005	7.29	0.028	0.010	4.51	0.023	0.005	8.03	0.028	0.016	5.25	0.023	0.011
66B	1	3.30	0.008	0.004	4.00	0.015	0.009	0.70	0.007	0.005	4.00	0.015	0.009	0.70	0.007	0.005
50	1	0.44	NA	NA	5.53	0.154	0.090	5.09	NA	NA	4.48	0.093	0.063	4.04	NA	NA
62	1	0.99	0.004	0.002	20.19	0.125	0.046	19.20	0.121	0.044	9.75	0.048	0.032	8.76	0.044	0.030
35	1	2.30	0.026	0.018	6.59	0.108	0.038	4.29	0.082	0.020	28.97	0.235	0.067	26.67	0.209	0.049
73	1	5.13	0.009	0.035	4.35	0.028	0.002	-0.78	0.019	-0.033	4.35	0.028	0.022	-0.78	0.019	-0.013
59	1	0.00	0.009	0.001	1.71	0.021	0.001	1.71	0.012	0.000	8.51	0.050	0.026	8.51	0.041	0.025
58	1	1.94	0.006	0.001	9.35	0.260	0.138	7.41	0.254	0.137	6.69	0.187	0.119	4.75	0.181	0.118
51	1	0.00	0.007	0.001	0.64	0.053	0.021	0.64	0.046	0.020	28.04	0.026	0.001	28.04	0.019	0.000
23	1	17.94	0.040	0.008	18.18	0.112	0.020	0.24	0.072	0.012	11.21	0.043	0.008	-6.73	0.003	0.000
79	1	7.51	0.014	0.001	8.56	0.124	0.013	1.05	0.110	0.012	7.08	0.040	0.015	-0.43	0.026	0.014
74A	1	1.23	0.004	0.001	3.76	0.012	0.001	2.53	0.008	0.000	3.02	0.010	0.002	1.79	0.006	0.001
77	1	0.00	0.049	0.032	4.56	0.086	0.050	4.56	0.037	0.018	7.75	0.029	0.004	7.75	-0.020	-0.028
25	1	0.00	0.003	0.002	24.00	0.115	0.015	24.00	0.112	0.013	3.42	0.129	0.079	3.42	0.126	0.077
7	1	6.02	0.023	0.009	5.38	0.130	0.012	-0.64	0.107	0.003	4.19	0.073	0.028	-1.83	0.050	0.019
66A	1	2.13	0.011	0.002	17.84	0.056	0.009	15.71	0.045	0.007	4.90	0.022	0.009	2.77	0.011	0.007
78	1	4.81	0.005	0.003	6.92	0.046	0.024	2.11	0.041	0.021	2.03	0.022	0.001	-2.78	0.017	-0.002
40	1	0.00	0.007	0.001	NA	0.162	0.043	NA	0.155	0.042	22.89	0.068	0.028	22.89	0.061	0.027
5	2	0.00	0.001	0.001	49.93	1.110	0.187	49.93	1.109	0.186	3.18	0.450	0.300	3.18	0.449	0.299
4	2	18.72	0.007	0.001	22.49	0.057	0.012	3.77	0.050	0.011	22.71	0.143	0.101	3.99	0.136	0.100
19	2	10.92	0.003	0.001	27.58	0.775	0.145	16.66	0.772	0.144	9.31	0.087	0.041	-1.61	0.084	0.040
49	2	12.14	0.014	0.011	10.42	0.270	0.144	-1.72	0.256	0.133	9.47	0.298	0.184	-2.67	0.284	0.173
15	2	4.49	0.008	0.006	5.34	0.255	0.179	0.85	0.247	0.173	1.67	0.390	0.176	-2.82	0.382	0.170
24	2	2.02	0.003	0.002	3.64	0.046	0.036	1.62	0.043	0.034	0.00	0.037	0.024	-2.02	0.034	0.022
14	2	0.14	0.013	0.004	6.27	0.180	0.082	6.13	0.167	0.078	0.00	0.160	0.085	-0.14	0.147	0.081
2	2	0.26	0.004	0.002	4.02	0.324	0.128	3.76	0.320	0.126	4.11	0.108	0.066	3.85	0.104	0.064
6	2	0.00	0.045	0.023	7.17	1.700	0.350	7.17	1.655	0.327	0.00	0.525	0.430	0.00	0.480	0.407
56	2	0.18	0.007	0.002	12.48	0.160	0.073	12.30	0.153	0.071	4.60	0.268	0.124	4.42	0.261	0.122
47	2	6.28	0.030	0.021	11.66	0.300	0.124	5.38	0.270	0.103	8.13	0.158	0.114	1.85	0.128	0.093

CANADIAN AQUACULTURE SYSTEMS

APPENDIX II (cont'd)
Water Quality Data from Participating Fish Farms

FARM	GRP	INFLUENT (SOURCE)			PRODUCTION EFFLUENT			NET PROD'N EFFLUENT			FARM EFFLUENT			NET FARM EFFLUENT		
		[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]
27A	3	2.58	0.003	0.001	17.64	0.244	0.031	15.06	0.241	0.030	4.12	0.305	0.265	1.54	0.302	0.264
18	3	1.79	0.002	0.001	13.04	0.096	0.020	11.25	0.094	0.019	11.71	0.106	0.026	9.92	0.104	0.025
52	3	0.00	0.053	0.001	28.44	0.225	0.001	28.44	0.172	0.000	13.07	0.186	0.001	13.07	0.133	0.000
31	3	2.49	0.006	0.003	6.28	0.105	0.063	3.79	0.099	0.060	2.70	0.044	0.041	0.21	0.038	0.038
45	3	0.21	0.009	0.004	4.72	0.115	0.058	4.51	0.106	0.054	3.27	0.148	0.099	3.06	0.139	0.095
28	3	2.44	0.011	0.004	3.33	0.010	0.002	0.89	-0.001	-0.002	13.44	0.084	0.001	11.00	0.073	-0.003
16	3	1.72	0.005	0.003	6.49	0.160	0.002	4.77	0.155	-0.001	6.21	0.120	0.020	4.49	0.115	0.017
20	3	0.64	0.003	0.002	32.67	0.184	0.066	32.03	0.181	0.064	0.36	0.077	0.049	-0.28	0.074	0.047
12	3	0.00	0.046	0.014	19.05	0.186	0.076	19.05	0.140	0.062	5.08	0.155	0.081	5.08	0.109	0.067
29	3	3.47	0.003	0.001	9.13	0.177	0.045	5.66	0.174	0.044	2.77	0.139	0.083	-0.70	0.136	0.082
34	3	3.49	0.005	0.003	34.09	0.725	0.098	30.60	0.720	0.095	3.99	0.106	0.047	0.50	0.101	0.044
22	3	1.61	0.002	0.002	11.72	0.175	0.046	10.11	0.173	0.044	4.18	0.147	0.083	2.57	0.145	0.081
10	3	0.00	0.030	0.005	13.54	0.064	0.005	13.54	0.034	0.000	9.15	0.058	0.026	9.15	0.028	0.021
42	4	0.00	0.012	0.001	6.69	0.017	0.001	6.69	0.005	0.000	3.40	0.020	0.001	3.40	0.008	0.000
32B	4	7.74	0.048	0.028	8.51	0.054	0.023	0.77	0.006	-0.005	8.51	0.054	0.023	0.77	0.006	-0.005
67	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.27	0.027	0.005	NA	NA	NA
46	4	2.38	0.011	0.010	19.53	0.108	0.003	17.15	0.097	-0.007	4.23	0.027	0.001	1.85	0.016	-0.009
68	4	30.37	0.058	0.009	5.10	0.007	0.005	-25.27	-0.051	-0.004	5.10	0.007	0.005	-25.27	-0.051	-0.004
53	4	1.61	0.005	0.001	14.44	0.038	0.001	12.83	0.033	0.000	14.44	0.038	0.001	12.83	0.033	0.000
69	4	4.92	0.018	0.008	7.76	0.049	0.017	2.84	0.031	0.009	6.87	0.046	0.011	1.95	0.028	0.003
41	4	NA	NA	NA	4.15	0.024	0.001	NA	NA	NA	4.15	0.024	0.001	NA	NA	NA
70A	4	0.00	0.007	0.001	5.40	0.071	0.041	5.40	0.064	0.040	5.40	0.071	0.041	5.40	0.064	0.040
57	4	2.83	0.006	0.001	29.97	0.285	0.114	27.14	0.279	0.113	29.97	0.285	0.114	27.14	0.279	0.113
54	4	NA	NA	NA	5.48	0.026	0.013	NA	NA	NA	5.48	0.026	0.013	NA	NA	NA
17	4	6.69	0.098	0.058	26.42	0.250	0.046	19.73	0.152	-0.012	16.07	0.118	0.043	9.38	0.020	-0.015
13	4	0.00	0.008	0.001	23.27	0.170	0.005	23.27	0.162	0.004	23.27	0.170	0.005	23.27	0.162	0.004
61	4	5.95	0.044	0.001	23.02	0.084	0.001	17.07	0.040	0.000	23.02	0.084	0.001	17.07	0.040	0.000
38	4	0.56	0.009	0.001	0.54	0.018	0.001	-0.02	0.009	0.000	0.54	0.018	0.001	-0.02	0.009	0.000
11	4	0.00	0.001	0.006	9.19	0.042	0.005	9.19	0.041	-0.001	9.19	0.042	0.005	9.19	0.041	-0.001
37	4	0.68	0.008	0.001	1.01	0.008	0.001	0.33	0.000	0.000	1.01	0.008	0.001	0.33	0.000	0.000
65	4	3.28	0.007	0.001	6.63	0.019	0.001	3.35	0.012	0.000	12.88	0.059	0.001	9.60	0.052	0.000
71	4	5.10	0.011	0.005	11.76	0.030	0.003	6.66	0.019	-0.002	11.76	0.030	0.003	6.66	0.019	-0.002
48	4	12.46	0.052	0.033	11.37	0.260	0.099	-1.09	0.208	0.066	8.07	0.034	0.014	-4.39	-0.018	-0.019
72	4	4.96	0.013	0.003	7.15	0.022	0.003	2.19	0.009	0.000	7.15	0.002	0.003	2.19	-0.011	0.000
80	4	1.28	0.007	0.002	4.91	0.021	0.005	3.63	0.014	0.003	2.62	0.033	0.019	1.34	0.026	0.017
32A	4	3.61	0.039	0.027	6.76	0.068	0.034	3.15	0.029	0.007	6.76	0.068	0.034	3.15	0.029	0.007
64	4	NA	NA	NA	3.70	0.014	0.003	NA	NA	NA	6.82	0.029	0.002	NA	NA	NA

APPENDIX II (cont'd)
Water Quality Data from Participating Fish Farms

FARM	GRP	INFLUENT (SOURCE)			PRODUCTION EFFLUENT			NET PROD'N EFFLUENT			FARM EFFLUENT			NET FARM EFFLUENT		
		[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]	[TSS]	[TP]	[DP]
30	4	3.29	0.022	0.002	14.06	0.038	0.003	10.77	0.016	0.001	14.06	0.038	0.003	10.77	0.016	0.001
44	4	1.15	0.006	0.005	6.88	0.085	0.046	5.73	0.079	0.041	2.06	0.135	0.105	0.91	0.129	0.100
33	4	18.65	0.025	0.013	26.37	0.058	0.013	7.72	0.033	0.000	26.37	0.058	0.013	7.72	0.033	0.000
36	4	0.95	0.006	0.001	111.00	0.620	0.230	110.05	0.614	0.229	15.55	0.400	0.140	14.60	0.394	0.139
27B	4	3.05	0.062	0.035	4.75	0.055	0.028	1.70	-0.007	-0.007	4.75	0.055	0.025	1.70	-0.007	-0.010
70B	5	0.00	0.011	0.008	7.64	0.120	0.050	7.64	0.109	0.042	13.51	0.190	0.087	13.51	0.179	0.079
60	5	0.44	0.010	0.001	1.82	0.017	0.001	1.38	0.007	0.000	1.82	0.017	0.001	1.38	0.007	0.000
39	5	0.34	0.017	0.001	4.42	0.066	0.025	4.08	0.049	0.024	2.34	0.094	0.012	2.00	0.077	0.011
9	5	0.00	0.007	0.002	2.29	0.320	0.148	2.29	0.313	0.146	0.00	0.173	0.126	0.00	0.166	0.124
63	5	2.11	0.081	0.073	4.56	0.154	0.094	2.45	0.073	0.021	0.00	0.115	0.102	-2.11	0.034	0.029
81	5	6.55	0.010	0.001	21.62	0.058	0.015	15.07	0.048	0.014	21.62	0.058	0.015	15.07	0.048	0.014
82	5	4.04	0.006	0.001	5.28	0.117	0.087	1.24	0.111	0.086	0.00	0.105	0.090	-4.04	0.099	0.089
MEAN	1	Standard Raceways			8.81	0.109	0.029	5.10	0.089	0.017	9.33	0.074	0.032	5.62	0.057	0.021
MEAN	2	Oval Raceways			14.64	0.471	0.133	9.62	0.458	0.126	5.74	0.239	0.150	0.73	0.226	0.143
MEAN	3	Circular Tanks			15.40	0.190	0.039	13.82	0.176	0.036	6.16	0.129	0.063	4.59	0.115	0.060
MEAN	4	Earthen Ponds			13.99	0.088	0.026	9.34	0.065	0.016	9.68	0.069	0.022	4.88	0.045	0.012
MEAN	5	Others			6.80	0.122	0.060	4.88	0.101	0.048	5.61	0.107	0.062	3.69	0.087	0.049

CANADIAN AQUACULTURE SYSTEMS

APPENDIX III

Spearman's Correlation Matrix for Participating Fish Farms

SPEARMAN CORRELATION ANALYSIS - GROUP A (STANDARD RACEWAYS)

Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 21

	m1	m2	m3	mCOC	INTPT	r2	INTEN	PROD	AREA	DEPTH	CROP	DENS	FLOW	REUSE	TEMP	FWI	NH3	TKN	NO2	NO3	TP	OP	TSS	SIZE	HRT
m1	1.00000 0.0	0.73814 0.0001	0.81092 0.0001	-0.56122 0.0081	0.23319 0.3090	-0.45289 0.0392	-0.09224 0.6909	-0.14300 0.5363	0.01104 0.9621	-0.25779 0.2592	0.02793 0.9043	0.03638 0.8756	0.07382 0.7505	0.29552 0.1934	-0.06780 0.7703	-0.06236 0.7883	-0.22605 0.3245	-0.21630 0.3463	-0.51491 0.0169	-0.04501 0.8464	-0.32304 0.1532	-0.16591 0.4723	-0.10266 0.6579	-0.27705 0.2240	-0.02079 0.9287
m2	0.73814 0.0001	1.00000 0.0	0.88304 0.0001	-0.69308 0.0005	0.14875 0.5199	-0.25081 0.2728	-0.02468 0.9154	0.13065 0.5724	0.11043 0.6337	-0.00802 0.9725	0.16499 0.4748	0.21306 0.3538	0.23642 0.3022	-0.14776 0.5227	-0.06486 0.7800	-0.05326 0.8186	0.22215 0.3331	0.03573 0.8770	-0.44944 0.0410	-0.11461 0.6208	-0.29119 0.2003	0.01561 0.9464	-0.09422 0.6846	-0.35300 0.1165	-0.11043 0.6337
m3	0.81092 0.0001	0.88304 0.0001	1.00000 0.0	-0.57356 0.0066	0.32673 0.1483	-0.27680 0.2245	0.06496 0.7797	0.02665 0.9087	0.10913 0.6377	-0.12238 0.5972	0.12601 0.5862	0.24034 0.2940	0.11545 0.6183	-0.03694 0.8737	0.00619 0.9787	0.04547 0.8448	0.09224 0.6909	0.02014 0.9310	-0.32963 0.1445	-0.07029 0.7621	-0.22684 0.3227	0.10540 0.6493	-0.00715 0.9755	-0.29889 0.1881	0.08055 0.7285
mCOC	-0.56122 0.0081	-0.69308 0.0005	-0.57356 0.0066	1.00000 0.0	-0.01948 0.9332	0.45794 0.0368	-0.06104 0.7927	0.14555 0.5290	0.18961 0.4104	0.32155 0.1552	0.12338 0.5942	-0.19740 0.3911	0.14044 0.5437	0.03693 0.8737	0.23982 0.2951	-0.03377 0.8845	-0.28571 0.2093	0.19740 0.3911	0.33116 0.1425	0.20422 0.3746	0.08902 0.7012	-0.10276 0.6576	-0.13576 0.5574	0.29586 0.1929	0.14805 0.5219
INTPT	0.23319 0.3090	0.14875 0.5199	0.32673 0.1483	-0.01948 0.9332	1.00000 0.0	0.30399 0.1803	0.22987 0.3161	-0.00715 0.9755	0.34545 0.1251	0.35899 0.1100	0.13636 0.5556	-0.13247 0.5670	0.04226 0.8557	0.25849 0.2579	-0.01629 0.9441	0.27273 0.2317	-0.09481 0.6827	-0.06364 0.7841	0.02814 0.9036	0.27829 0.2219	0.12476 0.5900	0.27902 0.2206	0.11302 0.6257	-0.21766 0.3432	0.38931 0.0819
r2	-0.45289 0.0392	-0.25081 0.2728	-0.27680 0.2245	0.45794 0.0368	0.30399 0.1803	1.00000 0.0	0.19422 0.3989	-0.03640 0.8755	0.06106 0.7926	0.36044 0.1085	0.05651 0.8078	0.06301 0.7861	0.00715 0.9754	-0.22164 0.3343	-0.15906 0.4910	0.19032 0.4086	-0.09094 0.6950	0.09484 0.6826	0.15123 0.5129	0.34763 0.1226	0.11147 0.6305	0.10215 0.6595	-0.23847 0.2979	-0.17503 0.4479	0.18772 0.4152
INTEN	-0.09224 0.6909	-0.02468 0.9154	0.06496 0.7797	-0.06104 0.7927	0.22987 0.3161	0.19422 0.3989	1.00000 0.0	0.03249 0.8888	0.09221 0.6910	0.24133 0.2919	0.32208 0.1545	0.50130 0.0206	-0.39792 0.0740	-0.11078 0.6326	-0.32193 0.1547	0.98701 0.0001	0.11948 0.6060	0.46234 0.0348	0.30826 0.1740	0.23260 0.3103	0.37167 0.0971	0.58407 0.0054	0.05521 0.8121	0.36234 0.1065	0.63247 0.0021
PROD	-0.14300 0.5363	0.13065 0.5724	0.02665 0.9087	0.14555 0.5290	-0.00715 0.9755	-0.03640 0.8755	0.03249 0.8888	1.00000 0.0	0.54776 0.0102	0.48130 0.0272	0.72775 0.0002	0.22937 0.3172	0.65517 0.0013	-0.24018 0.2943	0.09064 0.6960	0.01884 0.9354	0.05198 0.8229	0.17154 0.4572	0.09169 0.6926	-0.10356 0.6551	-0.08745 0.7062	-0.03319 0.8864	-0.28502 0.2105	0.06912 0.7659	-0.08967 0.6991
AREA	0.01104 0.9621	0.11043 0.6337	0.10913 0.6377	0.18961 0.4104	0.34545 0.1251	0.06106 0.7926	0.09221 0.6910	0.54776 0.0102	1.00000 0.0	0.71062 0.0003	0.83117 0.0001	-0.21558 0.3480	0.73537 0.0001	-0.18464 0.4230	0.36494 0.1038	0.07273 0.7541	-0.08831 0.7035	0.25325 0.2680	0.05039 0.8283	-0.00969 0.9667	0.07602 0.7433	0.11057 0.6333	0.08509 0.7138	0.17856 0.4387	0.32727 0.1476
DEPTH	-0.25779 0.2592	-0.00802 0.9725	-0.12238 0.5972	0.32155 0.1552	0.35899 0.1100	0.36044 0.1085	0.24133 0.2919	0.48130 0.0272	0.71062 0.0003	1.00000 0.0	0.60567 0.0036	-0.21259 0.3549	0.46488 0.0337	-0.01901 0.9348	0.11372 0.6236	0.24935 0.2757	0.09493 0.6823	0.39576 0.0758	0.30758 0.1750	0.26654 0.2428	0.09399 0.6853	0.24440 0.2857	-0.07088 0.7601	0.07212 0.7560	0.37169 0.0971
CROP	0.02793 0.9043	0.16499 0.4748	0.12601 0.5862	0.12338 0.5942	0.13636 0.5556	-0.05651 0.8078	0.32208 0.1545	0.72775 0.0002	0.83117 0.0001	0.60567 0.0036	1.00000 0.0	0.26494 0.2458	0.69246 0.0005	-0.29542 0.1936	0.05279 0.8202	0.28831 0.2050	-0.08052 0.7286	0.37143 0.0974	0.11650 0.6150	0.04569 0.8441	0.12671 0.5842	0.19317 0.4015	-0.10588 0.6478	0.18508 0.4219	0.19351 0.4007
DENS	0.03638 0.8756	0.21306 0.3538	0.24034 0.2940	-0.19740 0.3911	-0.13247 0.5670	0.06301 0.7861	0.50130 0.0206	0.22937 0.3172	-0.21558 0.3480	-0.21259 0.3549	0.26494 0.2458	1.00000 0.0	-0.11964 0.6055	-0.33235 0.1410	-0.51874 0.0160	0.45195 0.0397	0.04545 0.8449	0.29740 0.1904	0.16689 0.4696	0.00623 0.9786	0.13255 0.5668	0.23089 0.3139	-0.05911 0.7991	0.07234 0.7553	-0.19091 0.4071
FLOW	0.07382 0.7505	0.23642 0.3022	0.11545 0.6183	0.14044 0.5437	0.04226 0.8557	0.00715 0.9754	-0.39792 0.0740	0.65517 0.0013	0.73537 0.0001	0.46488 0.0337	0.69246 0.0005	-0.11964 0.6055	1.00000 0.0	-0.25883 0.2573	0.32366 0.1524	-0.42458 0.0551	-0.12224 0.5976	0.08388 0.7178	-0.10944 0.6368	-0.03085 0.8944	-0.30416 0.1801	-0.22664 0.3232	-0.12228 0.5975	-0.04861 0.8342	-0.28023 0.2185
REUSE	0.29552 0.1934	-0.14776 0.5227	-0.03694 0.8737	0.03693 0.8737	0.25849 0.2579	-0.22164 0.3343	-0.11078 0.6326	-0.24018 0.2943	-0.18464 0.4230	-0.01901 0.9348	-0.29542 0.1936	-0.33235 0.1410	-0.25883 0.2573	1.00000 0.0	0.00000 1.0000	0.03693 0.8737	-0.29542 0.1936	-0.18464 0.4230	0.27914 0.2204	0.35431 0.1151	-0.11085 0.6324	0.07398 0.7500	-0.07388 0.7503	0.03706 0.8733	0.00000 1.0000
TEMP	-0.06780 0.7703	-0.06486 0.7800	0.00619 0.9787	0.23982 0.2951	-0.01629 0.9441	-0.15906 0.4910	-0.32193 0.1547	0.09064 0.6960	0.36494 0.1038	0.11372 0.6236	0.05279 0.8202	-0.51874 0.0160	0.32366 0.1524	0.00000 1.0000	1.00000 0.0	-0.31281 0.1674	-0.00130 0.9955	-0.00782 0.9732	0.07718 0.7395	-0.08406 0.7171	-0.23411 0.3071	0.00359 0.9877	-0.01434 0.9508	0.26553 0.2447	0.00782 0.9732
FWI	-0.06236 0.7883	-0.05326 0.8186	0.04547 0.8448	-0.03377 0.8845	0.27273 0.2317	0.19032 0.4086	0.98701 0.0001	0.01884 0.9354	0.07273 0.7541	0.24935 0.2757	0.28831 0.2050	0.45195 0.0397	-0.42458 0.0551	0.03693 0.8737	-0.31281 0.1674	1.00000 0.0	0.07403 0.7498	0.43636 0.0480	0.34818 0.1219	0.29975 0.1868	0.34048 0.1310	0.58667 0.0052	0.00909 0.9688	0.38449 0.0853	0.62987 0.0022
NH3	-0.22605 0.3245	0.22215 0.3331	0.09224 0.6909	-0.28571 0.2093	-0.09481 0.6827	-0.09094 0.6950	0.11948 0.6060	-0.08831 0.7035	0.09493 0.6823	-0.08052 0.7286	0.04545 0.8449	-0.12224 0.5976	-0.29542 0.1936	-0.00130 0.9955	0.07403 0.7498	1.00000 0.0	0.43636 0.0480	0.12697 0.5834	-0.01315 0.9549	0.39181 0.0790	0.28460 0.2112	0.35772 0.1114	0.29295 0.1975	-0.09384 0.6858	0.02597 0.9110
TKN	-0.21630 0.3463	0.03573 0.8778	0.02014 0.9310	0.19740 0.3911	-0.06364 0.7841	0.09484 0.6826	0.46234 0.0348	0.17154 0.4572	0.25325 0.2680	0.39576 0.0758	0.37143 0.0974	0.29740 0.1904	0.08388 0.7178	-0.18464 0.4230	-0.00782 0.9732	0.43636 0.0480	0.43636 0.0480	1.00000 0.0	0.41952 0.0583	0.16614 0.4717	0.28460 0.2112	0.44423 0.0436	0.27606 0.2258	0.41382 0.0622	0.13247 0.5670
NO2	-0.51491 0.0169	-0.44944 0.0410	-0.32963 0.1445	0.33116 0.1425	0.02814 0.9036	0.15123 0.5129	0.30826 0.1740	0.09169 0.6926	0.05039 0.8283	0.30758 0.1750	0.11650 0.6150	0.16689 0.4696	-0.10944 0.6368	0.27914 0.2704	0.07718 0.7395	0.34818 0.1219	0.12697 0.5834	0.41952 0.0583	1.00000 0.0	0.34293 0.1280	0.26327 0.2489	0.69257 0.0005	0.04779 0.8370	0.43022 0.0516	0.06545 0.7781
NO3	-0.04501 0.8464	-0.11461 0.6208	-0.07029 0.7621	0.20422 0.3746	0.27829 0.2219	0.34763 0.1226	0.23260 0.3103	-0.10356 0.6551	-0.00969 0.9667	0.26654 0.2428	0.04569 0.8441	0.00623 0.9786	-0.03085 0.8944	0.35431 0.1151	-0.08406 0.7171	0.29975 0.1868	-0.01315 0.9549	0.16614 0.4717	0.34293 0.1280	1.00000 0.0	-0.21890 0.3404	0.23749 0.2999	-0.08067 0.7201	-0.11568 0.6176	0.10069 0.6391
TP	-0.32304 0.1532	-0.29119 0.2003	-0.22684 0.3227	0.08902 0.7012	0.12476 0.5900	0.11147 0.6305	0.37167 0.0971	-0.08745 0.7062	0.07602 0.7433	0.09399 0.6853	0.12671 0.5842	0.13255 0.5668	-0.30416 0.1801	-0.11085 0.6324	-0.23411 0.3071	0.34048 0.1310	0.39181 0.0790	0.28460 0.2112	0.26327 0.2489	-0.21890 0.3404	1.00000 0.0	0.44842 0.0415	0.40706 0.0664	0.00946 0.9676	0.33708 0.1341
OP	-0.16591 0.4723	0.01561 0.9464	0.10540 0.6493	-0.10276 0.6576	0.27902 0.2206	0.10215 0.6595	0.58407 0.0054	-0.03319 0.8864	0.11057 0.6333	0.24440 0.2857	0.19317 0.4015	0.23089 0.3139	-0.22664 0.3232	0.07398 0.7500	0.00359 0.9877	0.58667 0.0052	0.35772 0.1114	0.44423 0.0436	0.69257 0.0005	0.23749 0.2999	0.44842 0.0415	1.00000 0.0	0.07742 0.7387	0.27872 0.2211	0.32976 0.1443
TSS	-0.10266 0.6579	-0.09422 0.6846	-0.00715 0.9755	-0.13576 0.5574	0.11302 0.6257	-0.23847 0.2979	0.05521 0.8121	-0.28502 0.2105	0.08509 0.7138	-0.07088 0.7601	-0.10588 0.6478	-0.05911 0.7991	-0.12228 0.5975	-0.07388 0.7503	-0.01434 0.9508	0.00909 0.9688	0.29295 0.1975	0.27606 0.2258	0.04779 0.8370	-0.08067 0.7201	0.40706 0.0664	0.07742 0.7387	1.00000 0.0	0.00945 0.9676	0.10913 0.6377
SIZE	-0.27705 0.2240	-0.35300 0.1165	-0.29889 0.1881	0.29586 0.1929	-0.21766 0.3432	-0.17503 0.4479	0.36234 0.1065	0.06912 0.7659	0.17856 0.4387	0.07212 0.7560	0.18508 0.4219	0.07234 0.7553	-0.04861 0.8342	0.03706 0.8733	0.26553 0.2447	0.38449 0.0853	-0.09384 0.6858	0.41382 0.0622	0.43022 0.0516	-0.11568 0.6176	0.00946 0.9676	0.27872 0.2211	0.00945 0.9676	1.00000 0.0	0.17139 0.4576
HRT	-0.02079 0.9287	-0.11043 0.6337	0.08055 0.7285	0.14805 0.5219	0.38831 0.0819	0.18772 0.4152	0.63247 0.0021	-0.08967 0.6991	0.32727 0.1476	0.37169 0.0971	0.19351 0.4007	-0.19091 0.4071	-0.28023 0.2185	0.00000 1.0000	0.00782 0.9732	0.62987 0.0022	0.02597 0.9110	0.13247 0.5670	0.06545 0.7781	0.10069 0.6391	0.33708 0.1341	0.32976 0.1443	0.10913 0.6377	0.17139 0.4576	1.00000 0.0

SPEARMAN CORRELATION ANALYSIS - GROUP B (OVAL RACEWAYS)

Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 11

	m1	m2	m3	mCOC	INJPT	r2	INTEN	PROO	AREA	DEPTH	CROP	OENS	FLOW	REOSE	TEMP	FWI	NH3	TKN	NO2	NO3	TP	OP	TSS	SIZE	HRT
m1	1.00000 0.0	0.90909 0.0001	0.37273 0.2589	-0.78182 0.0045	-0.34545 0.2981	-0.44647 0.1686	-0.16364 0.6307	0.03636 0.9155	0.29613 0.3266	-0.12808 0.6004	-0.40000 0.2229	-0.46364 0.1509	-0.38182 0.2466	-0.19771 0.5601	0.26028 0.4395	-0.45455 0.1601	-0.62727 0.0388	-0.55455 0.0767	0.02727 0.9306	0.01822 0.9576	-0.21818 0.5192	-0.48182 0.1334	-0.41818 0.2006	-0.01835 0.9573	-0.04545 0.8934
m2	0.90909 0.0001	1.00000 0.0	0.26364 0.4334	-0.67273 0.0233	-0.06364 0.8525	-0.40547 0.2160	-0.12727 0.7092	-0.11818 0.7293	0.08200 0.8106	-0.21461 0.5263	-0.41818 0.2006	-0.51818 0.1025	-0.48182 0.1334	-0.05927 0.8614	0.33334 0.3165	-0.33636 0.3118	-0.62727 0.0388	-0.51818 0.1025	0.14545 0.6696	-0.00911 0.9788	-0.12727 0.7092	-0.38182 0.2466	-0.30000 0.3701	-0.11010 0.7473	-0.08182 0.8110
m3	0.37273 0.2589	0.26364 0.4334	1.00000 0.0	-0.30000 0.3701	0.03636 0.9155	0.40547 0.2160	0.09091 0.7904	0.15455 0.6500	0.18223 0.5918	0.05936 0.8624	0.19091 0.5739	0.12727 0.7092	0.17273 0.6115	0.12415 0.7161	-0.10046 0.7688	0.13636 0.6893	-0.31818 0.3403	-0.38182 0.2466	0.13636 0.6893	0.38724 0.2393	-0.10000 0.7699	-0.07273 0.8317	-0.57273 0.0655	-0.09175 0.7885	-0.15455 0.6500
mCOC	-0.78182 0.0045	-0.67273 0.0233	-0.30000 0.3701	1.00000 0.0	0.60909 0.0467	0.45103 0.1638	0.13636 0.6893	0.12727 0.7092	-0.38269 0.2454	0.00913 0.9787	0.31818 0.3403	0.51818 0.1025	0.20909 0.5372	-0.12874 0.7060	-0.23745 0.4820	0.25455 0.4500	0.69091 0.0186	0.39091 0.2345	-0.41818 0.2006	-0.14123 0.6787	0.17273 0.6115	0.41818 0.2006	0.15455 0.6500	0.14680 0.6667	-0.15455 0.6500
INJPT	-0.34545 0.2981	-0.06364 0.8525	0.03636 0.9155	0.60909 0.0467	1.00000 0.0	0.40091 0.2217	0.40000 0.2229	0.01818 0.9577	-0.23690 0.4831	0.00000 1.0000	0.37273 0.2589	0.34545 0.2981	-0.18182 0.5926	0.00460 0.9893	0.21918 0.5173	0.50909 0.1097	0.52727 0.0956	0.39091 0.2345	-0.03636 0.9155	-0.13212 0.6986	0.33636 0.3118	0.54545 0.0827	-0.10000 0.7699	0.22937 0.4975	0.03636 0.9155
r2	-0.44647 0.1686	-0.40547 0.2160	0.40547 0.2160	0.45103 0.1638	0.40091 0.2217	1.00000 0.0	0.35535 0.2835	0.06834 0.8418	-0.42237 0.1956	-0.11899 0.7275	0.44191 0.1736	0.56492 0.0702	0.09567 0.7796	-0.05761 0.8664	-0.23341 0.4897	0.32802 0.3247	0.35991 0.2769	0.26879 0.4242	0.20501 0.5454	-0.15068 0.6583	0.45558 0.1591	0.39180 0.2334	-0.20501 0.5454	-0.23449 0.4877	-0.34624 0.2969
INTEN	-0.16364 0.6307	-0.12727 0.7092	0.09091 0.7904	0.13636 0.6893	0.40000 0.2229	0.35535 0.2835	1.00000 0.0	0.40000 0.2229	0.41002 0.2104	0.22831 0.4995	0.88182 0.0003	0.69091 0.0186	-0.08182 0.8110	-0.23450 0.4876	0.10959 0.7484	0.74545 0.0085	0.50909 0.1097	0.62727 0.0388	0.49091 0.1252	-0.39180 0.2334	0.71818 0.0128	0.77273 0.0053	-0.31818 0.3403	0.43121 0.1854	0.39091 0.2345
PROO	0.03636 0.9155	-0.11818 0.7293	0.15455 0.6500	0.12727 0.7092	0.01818 0.9577	0.06834 0.8418	0.40000 0.2229	1.00000 0.0	0.22779 0.5005	-0.28767 0.3910	0.60000 0.0510	0.60909 0.0467	0.42273 0.1420	-0.02259 0.9358	-0.51142 0.1078	0.36364 0.2716	0.32727 0.3259	0.18182 0.5926	-0.21818 0.5192	0.08656 0.8002	0.13636 0.6893	0.26364 0.4334	-0.27273 0.4053	0.01835 0.9573	0.13636 0.6893
AREA	0.29613 0.3766	0.08200 0.8106	0.18223 0.5918	-0.38269 0.2454	-0.23690 0.4831	-0.42237 0.1956	0.41002 0.2104	0.22779 0.5005	1.00000 0.0	0.59039 0.0558	0.35535 0.2835	0.12301 0.7186	-0.04556 0.8942	-0.24195 0.4735	0.27689 0.4098	0.25057 0.4574	-0.00456 0.9894	0.09112 0.7899	0.09567 0.7796	-0.02511 0.9416	-0.06834 0.8418	0.13212 0.6986	-0.20046 0.5545	0.74025 0.0092	0.67426 0.0229
DEPTH	-0.12808 0.6004	-0.21461 0.5263	0.05936 0.8624	0.00913 0.9787	0.00000 1.0000	-0.11899 0.7275	0.22831 0.4995	-0.28767 0.3910	0.59039 0.0558	1.00000 0.0	0.22831 0.4995	-0.10502 0.7586	-0.12786 0.7079	0.03002 0.9302	0.05734 0.8670	0.35160 0.2890	0.06393 0.8519	0.14155 0.6780	0.23288 0.4907	-0.20595 0.5435	0.05480 0.8729	0.33790 0.3095	0.31964 0.3380	0.51153 0.1078	0.69864 0.0168
CROP	-0.40000 0.2229	-0.41818 0.2006	0.19091 0.5739	0.31818 0.3403	0.37273 0.2589	0.44191 0.1736	0.88182 0.0003	0.60000 0.0510	0.35535 0.2835	0.22831 0.4995	1.00000 0.0	0.82727 0.0017	0.34545 0.2981	0.02295 0.9465	-0.22831 0.4995	0.87273 0.0005	0.58182 0.0604	0.60000 0.0510	0.32727 0.3259	-0.08656 0.8002	0.56364 0.0710	0.79091 0.0037	-0.38182 0.2466	0.30277 0.3655	0.36364 0.2716
OENS	-0.46364 0.1509	-0.51818 0.1025	0.12727 0.7092	0.51818 0.1025	0.34545 0.2981	0.56492 0.0702	0.69091 0.0186	0.60909 0.0467	0.12301 0.7186	-0.10502 0.7586	0.82727 0.0017	1.00000 0.0	0.36364 0.2716	-0.28508 0.3955	-0.17808 0.6004	0.53636 0.0890	0.54545 0.0827	0.40909 0.2115	-0.05455 0.8734	-0.04100 0.9047	0.30909 0.3550	0.46364 0.1509	-0.41636 0.1797	0.29359 0.3809	-0.05455 0.8734
FLOW	-0.38182 0.2466	-0.48182 0.1334	0.17273 0.6115	0.20909 0.5372	-0.18182 0.5926	0.09567 0.7796	-0.08182 0.8110	0.42273 0.1420	-0.04556 0.8942	-0.12786 0.7079	0.34545 0.2981	0.36364 0.2716	1.00000 0.0	0.55176 0.0785	-0.65297 0.0294	0.30000 0.3701	0.03636 0.9155	-0.06364 0.8525	-0.10000 0.7699	0.73349 0.0102	-0.19091 0.5739	0.06364 0.8525	-0.10909 0.7495	-0.30277 0.3655	-0.18182 0.5926
REOSE	-0.19771 0.5601	-0.05927 0.8614	0.12415 0.7161	-0.12874 0.7060	0.00460 0.9893	-0.05761 0.8664	-0.23450 0.4876	-0.02759 0.9358	-0.24195 0.4735	0.03002 0.9302	0.02299 0.9465	-0.28508 0.3955	0.55176 0.0785	1.00000 0.0	-0.43419 0.1821	0.39083 0.2346	-0.17472 0.6074	-0.03219 0.9252	0.35405 0.2854	0.58989 0.0561	-0.04138 0.9038	0.13794 0.6859	0.16093 0.6364	-0.58933 0.0564	0.10575 0.7570
TEMP	0.26028 0.4395	0.33334 0.3165	-0.10046 0.7688	-0.23745 0.4820	0.21918 0.5173	-0.23341 0.4897	0.10959 0.7484	-0.51142 0.1078	0.27689 0.4098	0.05734 0.8670	-0.22831 0.4995	-0.17808 0.6004	-0.65297 0.0294	-0.43419 0.1821	1.00000 0.0	-0.18722 0.5815	-0.02740 0.9363	0.10046 0.7688	0.07761 0.8205	-0.17163 0.6139	-0.03653 0.9151	-0.12786 0.7079	0.24658 0.4648	0.57604 0.0636	0.06393 0.8519
FWI	-0.45455 0.1601	-0.33636 0.3118	0.13636 0.6893	0.25455 0.4500	0.50909 0.1097	0.32802 0.3247	0.74545 0.0085	0.36364 0.2716	0.25057 0.4574	0.35160 0.2890	0.87273 0.0005	0.53636 0.0890	0.30000 0.3701	0.39083 0.2346	-0.18722 0.5815	1.00000 0.0	0.50000 0.1173	0.60909 0.0467	0.48182 0.1334	0.01367 0.9682	0.52727 0.0956	0.83636 0.0013	-0.18182 0.5926	0.16514 0.6275	0.52727 0.0956
NH3	-0.62727 0.0388	-0.62727 0.0388	-0.31818 0.3403	0.69091 0.0186	0.52727 0.0956	0.35991 0.2769	0.50909 0.1097	0.32727 0.3259	-0.00456 0.9894	0.06393 0.8519	0.58182 0.0604	0.54545 0.0827	0.03636 0.9155	-0.17472 0.6074	-0.02740 0.9363	0.50000 0.1173	1.00000 0.0	0.89091 0.0002	-0.08182 0.8110	-0.38724 0.2393	0.59091 0.0556	0.76364 0.0062	0.02727 0.9366	0.33946 0.3071	0.27273 0.4171
TKN	-0.55455 0.0767	-0.51818 0.1025	-0.38182 0.2466	0.39091 0.2345	0.39091 0.2345	0.26879 0.4242	0.62727 0.0388	0.18182 0.5926	0.09112 0.7899	0.14155 0.6780	0.60000 0.0510	0.40909 0.2115	-0.06364 0.8525	-0.03219 0.9252	0.10046 0.7688	0.60909 0.0467	0.89091 0.0002	1.00000 0.0	0.31818 0.3403	-0.44647 0.1686	0.75455 0.0073	0.83636 0.0013	0.16364 0.6307	0.27524 0.4127	0.43636 0.1797
NO2	0.02727 0.9366	0.14545 0.6696	0.13636 0.6893	-0.41818 0.2006	-0.03636 0.9155	0.20501 0.5454	0.49091 0.1252	-0.21818 0.5192	0.09567 0.7796	0.23288 0.4907	0.32727 0.3259	-0.05455 0.8734	-0.10000 0.7699	0.35405 0.2854	0.07763 0.8205	0.48182 0.1334	-0.08182 0.8110	0.31818 0.3403	1.00000 0.0	-0.14579 0.6689	0.63636 0.0353	0.46364 0.1509	0.17273 0.6115	-0.21102 0.5334	0.23636 0.4841
NO3	0.01822 0.9576	-0.00911 0.9788	0.38724 0.2393	-0.14123 0.6787	-0.13212 0.6986	-0.15068 0.6583	-0.39180 0.2334	0.08656 0.8002	-0.02511 0.9416	-0.20595 0.5435	-0.08656 0.8002	-0.04100 0.9047	0.73349 0.0102	0.58989 0.0561	-0.17163 0.6139	0.01367 0.9682	-0.38724 0.2393	-0.44647 0.1686	-0.14579 0.6689	1.00000 0.0	-0.56037 0.0730	-0.34624 0.2969	-0.05923 0.8627	-0.25288 0.4531	-0.31891 0.3391
TP	-0.21818 0.5192	-0.12727 0.7092	-0.10000 0.7699	0.17273 0.6115	0.33636 0.3118	0.45558 0.1591	0.71818 0.0128	0.13636 0.6893	-0.06834 0.8418	0.05480 0.8729	0.56364 0.0710	0.30909 0.3550	-0.19091 0.5739	-0.04138 0.9038	-0.03653 0.9151	0.52727 0.0956	0.59091 0.0556	0.75455 0.0073	0.63636 0.0353	-0.56037 0.0730	1.00000 0.0	0.83636 0.0013	0.01818 0.9577	-0.02752 0.9360	0.18182 0.5926
OP	-0.48182 0.1334	-0.38182 0.2466	-0.07273 0.8317	0.41818 0.2006	0.54545 0.0827	0.39180 0.2334	0.77273 0.0053	0.26364 0.4334	0.13212 0.6986	0.33790 0.3095	0.79091 0.0037	0.46364 0.1509	0.06364 0.8525	0.13794 0.6859	-0.12786 0.7079	0.83636 0.0013	0.76364 0.0062	0.83636 0.0013	0.46364 0.1509	-0.34624 0.2969	0.83636 0.0013	1.00000 0.0	0.09909 0.9788	0.21162 0.5334	0.45455 0.1601
TSS	-0.41818 0.2006	-0.30000 0.3701	-0.57273 0.0655	0.15455 0.6500	-0.10000 0.7699	-0.20501 0.5454	-0.31818 0.3403	-0.77273 0.0053	-0.20046 0.5545	0.31964 0.3380	-0.38182 0.2466	-0.41636 0.1797	-0.10909 0.7495	0.16093 0.6364	0.24658 0.4648	-0.18182 0.5926	0.02727 0.9366	0.16364 0.6307	0.17273 0.6115	-0.05923 0.8627	0.01818 0.9577	0.09909 0.9788	1.00000 0.0	0.80917 0.9786	-0.09909 0.9788
SIZE	-0.01835 0.9573	-0.11010 0.7473	-0.09175 0.7885	0.14680 0.6667	0.22937 0.4975	-0.23449 0.4877	0.43121 0.1854	0.01835 0.9573	0.74025 0.0092	0.51153 0.1078	0.30277 0.3655	0.29359 0.3809	-0.30277 0.3655	-0.58933 0.0564	0.57604 0.0636	0.16514 0.6275	0.33946 0.3071	0.27524 0.4127	-0.21102 0.5334	-0.25288 0.4531	-0.02752 0.9360	0.21162 0.5334	0.80917 0.9786	1.00000 0.0	0.47708 0.1379
HRT	-0.04545 0.8944	-0.08182 0.8110	-0.15455 0.6500	-0.15455 0.6500	0.03636 0.9155	-0.34624 0.2969	0.39091 0.2345	0.13636 0.6893	0.67426 0.0229	0.69864 0.0168	0.36364 0.2716	-0.05455 0.8734	-0.18182 0.5926	0.10575 0.7570	0.06393 0.8519	0.52727 0.0956	0.27273 0.4171	0.43636 0.1797	0.23636 0.4841	-0.31891 0.3391	0.18182 0.5926	0.45455 0.1601	-0.09909 0.9788	0.47708 0.1379	1.00000 0.0

SPEARMAN CORRELATION ANALYSIS - GROUP C (CIRCULAR TANKS)

Spearman Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 12

	m1	m2	m3	mCOC	INTPT	r2	INTEN	PROD	AREA	DEPTH	CROP	DENS	FLOW	REUSE	TEMP	FWI	NH3	TKN	NO2	NO3	TP	OP	TSS	SIZE	HRI
m1	1.00000 0.0	0.95804 0.0001	0.60140 0.0386	-0.93706 0.0001	0.08392 0.7954	-0.18881 0.5567	0.02797 0.9312	-0.41958 0.1745	-0.28333 0.3722	-0.36364 0.2453	-0.09091 0.7787	0.16084 0.6175	-0.31918 0.3119	-0.21836 0.4954	-0.10158 0.7534	-0.01399 0.9656	-0.01399 0.9656	-0.36364 0.2453	-0.41568 0.1790	-0.16678 0.6044	0.08392 0.7954	-0.23860 0.4552	0.25874 0.4168	0.04895 0.8799	0.13986 0.6646
m2	0.95804 0.0001	1.00000 0.0	0.65035 0.0220	-0.91608 0.0001	0.04895 0.8799	-0.17483 0.5868	-0.13986 0.6646	-0.44056 0.1517	-0.25064 0.4320	-0.44755 0.1446	-0.17483 0.5868	0.07692 0.8122	-0.24825 0.4366	-0.21836 0.4954	0.03503 0.9139	-0.17483 0.5868	-0.18182 0.5717	-0.48252 0.1121	-0.50095 0.0971	-0.05076 0.8755	-0.02797 0.9312	-0.17544 0.5855	0.18881 0.5567	-0.02098 0.9484	0.05594 0.8629
m3	0.60140 0.0386	0.65035 0.0220	1.00000 0.0	-0.74825 0.0051	0.08392 0.7954	-0.07692 0.8122	0.00699 0.9828	-0.34965 0.2652	0.20705 0.5185	-0.11189 0.7292	0.27273 0.3911	0.21678 0.4986	0.20569 0.5213	0.48038 0.1139	0.00000 1.0000	0.04196 0.8970	-0.12587 0.6967	-0.03497 0.9141	-0.47964 0.1146	-0.15227 0.6366	0.41259 0.1826	0.15439 0.6319	0.37762 0.2262	0.08392 0.7954	0.0899 0.879
mCOC	-0.93706 0.0001	-0.91608 0.0001	-0.74825 0.0051	1.00000 0.0	0.00699 0.9828	0.34965 0.2652	-0.10490 0.7456	0.58042 0.0479	0.18525 0.5643	0.27972 0.3786	0.02098 0.9484	-0.16084 0.6175	0.26953 0.3969	0.13101 0.6848	-0.05254 0.8712	-0.06294 0.8459	-0.13986 0.6646	0.16084 0.6175	0.34818 0.2674	0.19578 0.5420	-0.31469 0.3191	0.02456 0.9396	-0.41259 0.1826	-0.23776 0.4568	-0.1818 0.571
INTPT	0.08392 0.7954	0.04895 0.8799	0.08392 0.7954	0.00699 0.9828	1.00000 0.0	0.19580 0.5419	-0.22273 0.3911	-0.11888 0.7129	0.03632 0.9108	-0.06993 0.8290	-0.06294 0.8459	-0.26573 0.4038	0.23407 0.4640	0.04367 0.8928	-0.02452 0.9397	-0.30070 0.3423	-0.27273 0.3911	-0.17483 0.5868	-0.16343 0.6118	0.26104 0.4125	-0.29371 0.3541	-0.28421 0.3706	-0.16783 0.6021	-0.02098 0.9484	-0.5604 0.054
r2	-0.18881 0.5567	-0.17483 0.5868	-0.07692 0.8122	0.34965 0.2652	0.19580 0.5419	1.00000 0.0	-0.44755 0.1446	0.72727 0.0074	0.42136 0.1725	-0.02797 0.9312	0.00699 0.9828	-0.13986 0.6646	0.26953 0.3969	0.30570 0.3339	-0.62697 0.0291	-0.33566 0.2861	-0.56643 0.0548	-0.19580 0.5419	-0.18475 0.5654	0.12327 0.7027	-0.39161 0.2081	-0.16842 0.6008	-0.22378 0.4845	-0.72727 0.0074	-0.1118 0.729
INTEN	0.02797 0.9312	-0.13986 0.6646	0.00699 0.9828	-0.10490 0.7456	-0.22273 0.3911	-0.44755 0.1446	1.00000 0.0	-0.00699 0.9828	-0.02906 0.9286	0.66434 0.0185	0.72028 0.0082	0.78322 0.0026	0.00709 0.9825	0.04367 0.8928	0.21366 0.5049	0.98601 0.0001	0.80420 0.0016	0.66434 0.0185	0.22738 0.4772	-0.31180 0.3238	0.77622 0.0030	0.32983 0.2951	0.45455 0.1377	0.39161 0.2081	0.3776 0.226
PROD	-0.41958 0.1745	-0.44056 0.1517	-0.34965 0.2652	0.58042 0.0479	-0.11888 0.7129	0.72727 0.0074	-0.00699 0.9828	1.00000 0.0	0.38867 0.2118	0.14685 0.6488	0.25175 0.4299	0.23776 0.4568	0.12767 0.6925	0.30570 0.3339	-0.50788 0.0918	0.08392 0.7954	-0.23776 0.4568	-0.00699 0.9828	0.06395 0.8435	0.15953 0.6204	-0.18182 0.5717	0.12281 0.7038	-0.47552 0.1182	-0.57343 0.0513	0.28671 0.366
AREA	-0.28333 0.3722	-0.25064 0.4320	0.20705 0.5185	0.18525 0.5643	0.03632 0.9108	0.42136 0.1725	-0.02906 0.9286	0.38867 0.2118	1.00000 0.0	0.37051 0.2358	0.51217 0.0887	0.05449 0.8664	0.58949 0.0437	0.40832 0.1876	-0.24016 0.4521	0.03632 0.9108	0.02906 0.9286	0.33055 0.2940	0.08858 0.7843	-0.23352 0.4651	0.36687 0.2408	0.20413 0.5245	0.02543 0.9375	0.15619 0.6278	-0.07991 0.8050
DEPTH	-0.36364 0.2453	-0.44755 0.1446	-0.11189 0.7292	0.27972 0.3786	-0.06993 0.8290	-0.02797 0.9312	0.66434 0.0185	0.14685 0.6488	0.37051 0.2358	1.00000 0.0	0.69930 0.0114	0.39860 0.1993	0.36174 0.2479	0.13101 0.6848	0.22417 0.4837	0.71329 0.0092	0.49650 0.1006	0.79021 0.0022	0.42634 0.1670	-0.33355 0.2894	0.58042 0.0479	0.31579 0.3173	0.52448 0.0800	0.26573 0.4038	0.0206 0.9484
CROP	-0.09091 0.7787	-0.17483 0.5868	0.27273 0.3911	0.02098 0.9484	-0.06294 0.8459	0.00699 0.9828	0.72028 0.0082	0.25175 0.4299	0.51217 0.0887	0.69930 0.0114	1.00000 0.0	0.79720 0.0019	0.62418 0.0301	0.48038 0.1139	0.04203 0.8968	0.76923 0.0034	0.40559 0.1908	0.54545 0.0666	-0.11014 0.7333	-0.35531 0.2571	0.72727 0.0074	0.23158 0.4689	0.39860 0.1993	0.18182 0.5717	0.00699 0.9828
DENS	0.16084 0.6175	0.07692 0.8122	0.21678 0.4986	-0.16084 0.6175	-0.26573 0.4038	-0.13986 0.6646	0.78322 0.0026	0.23776 0.4568	0.05449 0.8664	0.39860 0.1993	0.79720 0.0019	1.00000 0.0	0.26244 0.4099	0.21836 0.4954	0.11559 0.7206	0.81818 0.0011	0.37063 0.2356	0.23077 0.4705	-0.34463 0.2726	-0.05801 0.8579	0.55245 0.0625	0.19298 0.5479	0.23776 0.4568	-0.06993 0.8290	0.2517 0.4299
FLOW	-0.31918 0.3119	-0.24825 0.4366	0.20569 0.5213	0.26953 0.3969	0.23407 0.4640	0.26953 0.3969	0.00709 0.9825	0.12767 0.6925	0.58949 0.0437	0.36174 0.2479	0.62418 0.0301	0.26244 0.4099	1.00000 0.0	0.48725 0.1081	0.12079 0.7084	0.06384 0.8438	-0.18442 0.5661	0.12058 0.7089	-0.40360 0.1932	-0.14709 0.6483	0.17732 0.5814	-0.11033 0.7329	0.20569 0.5213	-0.04256 0.8955	-0.6738 0.0163
REUSE	-0.21836 0.4954	-0.21836 0.4954	0.48038 0.1139	0.13101 0.6848	0.04367 0.8928	0.30570 0.3339	0.04367 0.8928	0.30570 0.3339	0.40832 0.1876	0.13101 0.6848	0.48038 0.1139	0.21836 0.4954	0.48725 0.1081	1.00000 0.0	-0.34998 0.2648	0.13101 0.6848	-0.21836 0.4954	0.21836 0.4954	-0.17750 0.5810	-0.22642 0.4792	0.30570 0.3339	0.17530 0.5858	0.04367 0.8928	-0.13101 0.6848	0.0436 0.8928
TEMP	-0.10158 0.7534	0.03503 0.9139	0.00000 1.0000	-0.05254 0.8712	-0.02452 0.9397	-0.62697 0.0291	0.21366 0.5049	-0.50788 0.0918	-0.24016 0.4521	0.22417 0.4837	0.04203 0.8968	0.11559 0.7206	0.12079 0.7084	-0.34998 0.2648	1.00000 0.0	0.15762 0.6247	0.22767 0.4767	0.15061 0.6403	-0.00890 0.9781	0.30871 0.3289	0.12609 0.6962	0.40949 0.1862	0.22767 0.4767	0.29422 0.3533	-0.2697 0.3966
FWI	-0.01399 0.9656	-0.17483 0.5868	0.04196 0.8970	-0.06294 0.8459	-0.30070 0.3423	-0.33566 0.2861	0.98601 0.0001	0.08392 0.7954	0.03632 0.9108	0.71329 0.0092	0.76923 0.0034	0.81818 0.0011	0.06384 0.8438	0.13101 0.6848	0.15762 0.6247	1.00000 0.0	0.73427 0.0065	0.67133 0.0168	0.18830 0.5578	-0.29005 0.3605	0.77622 0.0030	0.34035 0.2790	0.46154 0.1309	0.20671 0.3663	0.3986 0.1993
NH3	-0.01399 0.9656	-0.18182 0.5717	-0.12587 0.6967	-0.13986 0.6646	-0.27273 0.3911	-0.56643 0.0548	0.80420 0.0016	-0.23776 0.4568	0.02906 0.9286	0.49650 0.1006	0.40559 0.1908	0.37063 0.2356	-0.18442 0.5661	-0.21836 0.4954	0.22767 0.4767	0.73427 0.0065	1.00000 0.0	0.76224 0.0040	0.50806 0.0917	-0.37706 0.2270	0.77622 0.0030	0.38246 0.2198	0.47552 0.1182	0.69930 0.0114	0.3396 0.2652
TKN	-0.36364 0.2453	-0.48252 0.1121	-0.03497 0.9141	0.16084 0.6175	-0.17483 0.5868	-0.19580 0.5419	0.66434 0.0185	-0.00699 0.9828	0.33055 0.2940	0.79021 0.0022	0.54545 0.0666	0.23077 0.4705	0.12058 0.7089	0.21836 0.4954	0.15061 0.6403	0.67133 0.0168	0.76224 0.0040	1.00000 0.0	0.62885 0.0285	-0.42057 0.1734	0.78322 0.0026	0.57895 0.0406	0.58042 0.0479	0.51049 0.0899	0.2447 0.4433
NO2	-0.41568 0.1790	-0.50095 0.0971	-0.47964 0.1146	0.34818 0.2674	-0.16343 0.6118	-0.18475 0.5654	0.22738 0.4772	0.06395 0.8435	0.08858 0.7843	0.42634 0.1670	-0.11014 0.7333	-0.34463 0.2726	-0.40360 0.1932	-0.17750 0.5810	-0.00890 0.9781	0.18830 0.5578	0.50806 0.0917	0.62885 0.0285	1.00000 0.0	-0.30577 0.3338	0.21672 0.4987	0.36723 0.2403	0.04619 0.8867	0.49740 0.0999	0.3872 0.2136
NO3	-0.16678 0.6044	-0.05076 0.8755	-0.15227 0.6366	0.19578 0.5420	0.26104 0.4125	0.12327 0.7027	-0.31180 0.3238	0.15953 0.6204	-0.23352 0.4651	-0.33355 0.2894	-0.35531 0.2571	-0.05801 0.8579	-0.14709 0.6483	-0.22642 0.4792	0.30871 0.3289	-0.29005 0.3605	-0.37706 0.2270	-0.42057 0.1734	-0.30577 0.3338	1.00000 0.0	-0.50033 0.0976	0.17828 0.5793	-0.56559 0.0553	-0.50758 0.0921	-0.0362 0.9109
TP	0.08392 0.7954	-0.02797 0.9312	0.41259 0.1826	-0.31469 0.3191	-0.29371 0.3541	-0.39161 0.2081	0.77622 0.0030	-0.18182 0.5717	0.36687 0.2408	0.58042 0.0479	0.72727 0.0074	0.55245 0.0625	0.17732 0.5814	0.30570 0.3339	0.12609 0.6962	0.77622 0.0030	0.77622 0.0030	0.78322 0.0026	0.21672 0.4987	-0.50033 0.0976	1.00000 0.0	0.47369 0.1198	0.62937 0.0283	0.60140 0.0386	0.3356 0.2061
OP	-0.23860 0.4552	-0.17544 0.5855	0.15439 0.6319	0.02456 0.9396	-0.28421 0.3706	-0.16842 0.6008	0.32983 0.2951	0.12281 0.7038	0.20413 0.5245	0.31579 0.3173	0.23158 0.4689	0.19298 0.5479	-0.11033 0.7329	0.17530 0.5850	0.40949 0.1862	0.34035 0.2790	0.38246 0.2198	0.57895 0.0406	0.36723 0.2403	0.17828 0.5793	0.47369 0.1198	1.00000 0.0	0.13681 0.6715	0.15790 0.6241	0.473 0.119
TSS	0.25874 0.4168	0.18881 0.5567	0.37762 0.2262	-0.41259 0.1826	-0.16783 0.6021	-0.22378 0.4845	0.45455 0.1377	-0.47552 0.1182	0.02543 0.9375	0.52448 0.0800	0.39860 0.1993	0.23776 0.4568	0.20569 0.5213	0.04367 0.8928	0.22767 0.4767	0.46154 0.1309	0.47552 0.1182	0.58042 0.0479	0.04619 0.8867	-0.56559 0.0553	0.62937 0.0283	0.13684 0.6715	1.00000 0.0	0.32168 0.3079	-0.1019 0.74
SIZE	0.04895 0.8799	-0.02098 0.9484	0.08392 0.7954	-0.23776 0.4568	-0.02098 0.9484	-0.72727 0.0074	0.39161 0.2081	-0.57343 0.0513	0.15619 0.6278	0.26573 0.4038	0.18182 0.5717	-0.06993 0.8290	-0.04256 0.8955	-0.13101 0.6848	0.29422 0.3533	0.28671 0.3663	0.69930 0.0114	0.51049 0.0899	0.49740 0.0999	-0.50758 0.0921	0.60140 0.0386	0.15790 0.6241	0.32168 0.3079	1.00000 0.0	0.0279 0.931
HRI	0.13986 0.6646	0.05594 0.8629	0.04895 0.8799	-0.18182 0.5717	-0.56643 0.0548	-0.11189 0.7292	0.37762 0.2262	0.28671 0.3663	-0.07991 0.8050	0.02098 0.9484	0.00699 0.9828	0.25175 0.4299	-0.67383 0.0163	0.04367 0.8928	-0.26970 0.3966	0.39860 0.1993	0.34965 0.2652	0.24476 0.4433	0.38226 0.2136	-0.03676 0.9109	0.33566 0.2861	0.47369 0.1190	-0.10190 0.7456	0.02797 0.9312	1.0 0.0

APPENDIX IV
Effluent Treatment Facilities Data

FARM #	GROUP	TYPE	AREA	FLOW	Vo	INLET	OUTLET	HRT	DEPTH	SLOPE	INTERC	SIZE	TSS	NH3	TKN	NO2	NO3	TP	DP
3	1	1	74.3	18329	246.7	2.23	7516.8	5.34	0.91	0.4994	-0.2431	250	1.225	1.113	0.853	1.000	1.000	0.871	1.007
5	2	1	23.8	2749	115.5	5.07	563.7	12.97	1.04	0.6121	0.4028	341	0.000	1.297	1.114	0.368	0.120	2.200	2.833
6	2	1	47.6	11259	236.5	5.22	2308.7	6.51	1.07	0.8304	0.6301	450	0.000	1.138	0.707	0.909	0.321	0.309	1.229
8	1	1	3.0	393	131.0	1.30	820.8	5.81	0.53	0.6152	-0.4816	133	1.102	1.327	1.106	2.500	0.800	1.000	1.600
19	2	1	22.4	5237	233.8	3.74	1494.1	8.00	1.30	0.7067	0.0269	93	0.338	1.000	0.761	0.481	1.049	0.310	0.979
23	1	1	10.9	2618	240.2	2.51	954.4	5.47	0.91	0.8865	-0.5626	133	0.905	0.935	0.909	1.000	1.000	1.045	1.250
24	2	1	58.0	17020	293.4	1.86	2326.7	4.50	0.91	0.4641	0.1760	52	1.685	0.761	0.959	1.143	2.000	2.190	3.000
47	2	1	5.4	6186	1145.6	4.12	3691.5	1.00	0.81	0.3270	0.2774	113	0.548	0.327	0.735	1.034	1.200	0.833	0.984
55	1	1	26.0	982	37.8	4.94	1025.5	30.90	0.81	0.7771	-0.5019	510	0.352	1.111	0.897	0.333	1.227	0.529	2.300
70	5	1	16.7	1375	82.3	2.23	751.9	21.30	1.22	0.3522	-0.2688	135	0.651	0.945	0.807	0.727	1.071	0.658	1.060
82	5	1	13.0	2618	201.4	1.63	1227.0	5.45	0.76	0.7607	0.6077	170	0.948	0.986	0.990	1.000	1.000	0.964	1.012
35	1	2	12.3	1571	127.7	0.04	1230.5	9.74	0.86	1.0696	0.2626	360	1.138	1.100	1.036	1.827	1.000	1.259	0.842
7	1	2	26.0	2160	83.1	0.74	1012.4	7.03	0.41	0.6063	-0.2277	93	0.779	4.438	1.895	1.000	2.800	0.562	2.333
21	1	2	11.1	2095	188.7	3.40	547.0	6.88	0.90	0.8769	0.1208	426	0.742	3.474	0.517	0.857	3.000	0.487	4.167
62	1	2	31.2	393	12.6	0.01	1289.4	57.90	0.76	0.8308	-0.0337	242	0.483	0.519	0.724	1.462	0.967	0.384	0.696
66	1	2	69.1	1212	17.5	0.60	1325.5	56.70	0.69	0.5417	0.3136	90	0.275	0.953	0.825	1.000	1.000	0.393	1.000
18	3	3	65.7	1636	24.9	0.07	1708.5	35.24	3.66	1.2342	-0.3970	114	0.898	0.830	1.026	1.333	1.000	1.104	1.300
23	1	3	672.5	13092	19.5	0.38	5859.6	906.20	3.06	0.8865	-0.5626	133	0.681	0.191	0.610	0.400	1.000	0.368	0.320
19	2	4	26.3	1309	49.8	0.52	72.0	44.09	1.52	0.7067	0.0269	93	1.320	0.824	0.863	1.000	0.965	0.363	0.289
20	3	4	1.2	196	167.5	0.02	409.4	6.55	0.76	0.7809	-0.2835	3	1.565	1.769	1.018	1.000	1.000	1.414	1.625
28	3	4	0.7	1309	1870.0	0.02	2734.0	0.40	0.48	1.1291	0.7530	5	1.300	1.026	1.000	1.000	1.000	1.300	0.500
29	3	4	65.7	884	13.5	1.75	30.8	130.50	1.22	0.7393	-0.2779	370	0.705	0.879	0.901	0.700	1.037	1.444	1.520
34	3	4	65.7	1964	29.9	0.03	73.3	73.40	1.52	0.6039	-0.2629	193	0.272	0.319	0.341	6.140	8.000	0.246	0.480
45	3	4	64.4	1309	20.3	0.04	1367.0	70.20	0.99	1.2140	0.2605	182	0.693	0.308	0.435	2.182	0.909	1.287	1.707
50	1	4	1.2	524	436.7	0.02	820.8	4.50	1.37	0.4826	0.5803	242	0.904	0.945	0.938	1.500	1.000	0.994	1.047
56	2	4	5.9	982	166.4	0.02	2051.1	7.00	0.81	0.9455	0.5147	182	0.000	0.889	1.029	0.875	1.063	1.081	1.370

CANADIAN AQUACULTURE SYSTEMS

APPENDIX IV (cont'd)
Effluent Treatment Facilities Data

	AREA	FLOW	Vo	INLET	OUTLET	HRT	DEPTH	SLOPE	INTERC	SIZE	TSS	NH3	TKN	NO2	NO3	TP	DP
Type 1 - In-raceway (n=11)																	
TYPE 1 - MEAN	27.4	6251	269.5	3.17	2061.9	9.75	0.93	0.6210	0.0057	216	0.705	0.995	0.894	0.954	0.981	0.992	1.569
TYPE 1 - MIN	3.0	393	37.8	1.30	563.7	1.00	0.53	0.3270	-0.5626	52	0.000	0.327	0.707	0.333	0.120	0.309	0.979
TYPE 1 - MAX	74.3	18329	1145.6	5.22	7516.8	30.90	1.30	0.8865	0.6301	510	1.685	1.327	1.114	2.500	2.000	2.200	3.000
TYPE 1 - S.D.	21.9	6124	287.3	1.41	1939.2	8.42	0.21	0.1819	0.4230	146	0.502	0.262	0.133	0.560	0.464	0.618	0.737
Type 2 - External Rectangular (n=5)																	
TYPE 2 - MEAN	29.9	1486	85.9	0.96	1081.0	27.65	0.72	0.7851	0.0871	242	0.683	2.097	0.999	1.229	1.753	0.617	1.808
TYPE 2 - MIN	11.1	393	12.6	0.01	547.0	6.88	0.41	0.5417	-0.2277	90	0.275	0.519	0.517	0.857	0.967	0.384	0.696
TYPE 2 - MAX	69.1	2160	188.7	3.40	1325.5	57.90	0.90	1.0696	0.3136	426	1.138	4.438	1.895	1.827	3.000	1.259	4.167
TYPE 2 - S.D.	21.1	648	66.9	1.26	288.2	24.23	0.17	0.1911	0.1985	136	0.292	1.560	0.478	0.362	0.938	0.328	1.316
Type 3 - External Pond (n=2)																	
TYPE 3 - MEAN	369.1	7364	22.2	0.23	3784.1	470.72	3.36	1.0604	-0.4798	124	0.790	0.511	0.818	0.867	1.000	0.736	0.810
TYPE 3 - MIN	65.7	1636	19.5	0.07	1708.5	35.24	3.06	0.8865	-0.5626	114	0.681	0.191	0.610	0.400	1.000	0.368	0.320
TYPE 3 - MAX	672.5	13092	24.9	0.38	5859.6	906.20	3.66	1.2342	-0.3970	133	0.898	0.830	1.026	1.333	1.000	1.104	1.300
TYPE 3 - S.D.	303.4	5728	2.7	0.16	2075.6	435.48	0.30	0.1739	0.0828	10	0.108	0.320	0.208	0.466	0.000	0.368	0.490
Type 4 - External Circular (n=8)																	
TYPE 4 - MEAN	28.9	1060	344.3	0.30	944.8	42.08	1.08	0.8253	0.1639	159	0.845	0.870	0.816	1.800	1.872	1.016	1.067
TYPE 4 - MIN	0.7	196	13.5	0.02	30.8	0.40	0.48	0.4826	-0.2835	3	0.000	0.308	0.341	0.700	0.909	0.246	0.289
TYPE 4 - MAX	65.7	1964	1870.0	1.75	2734.0	130.50	1.52	1.2140	0.7530	370	1.565	1.769	1.029	6.140	8.000	1.444	1.707
TYPE 4 - S.D.	29.2	509	591.5	0.57	952.8	43.64	0.36	0.2366	0.3951	115	0.505	0.427	0.254	1.698	2.317	0.436	0.535

APPENDIX V

Ministry of the Environment Interim Guidelines

INTERIM ENVIRONMENTAL GUIDELINES FOR SALMONID* AQUACULTURE FACILITIES IN ONTARIO

1.0 BACKGROUND

The Ministry of the Environment has a legislated mandate for the management of surface and groundwater quality and quantity throughout the province. It has been established that fish culture operations have the potential to impact on all four of these areas. The Ministry's concerns, therefore, relate to both the taking of water from surface or groundwater sources and fair sharing among all users, and the discharge of wastewaters to receiving streams or back to the groundwater aquifer in a condition ensuring acceptability for the greatest variety of uses.

Competition among users for adequate water supplies for drinking, irrigation, recreation, aquaculture and so on, can place demands on some aquifers and streams resulting in complaints of interference among users. For this reason, the Ontario Water Resources Act, Section 20, requires a Permit to Take Water for most significant water uses and protects established uses from interference by more recent ones. A guideline relating to the requirements for a hydrogeologic study for the taking of groundwater for aquacultural purposes, is under preparation and will become a part of this publication. Surface water taking will be assessed on a site-by-site basis.

Wastewater discharges containing fish manure and uneaten feeds can have unacceptable water quality impacts. Waste solids tend to settle within or downstream from aquaculture facilities, smothering valuable habitat of fish and other organisms. There they decompose to consume oxygen or release nutrients which stimulate weed and algae growth, and generally interfere with other uses of the water. Therefore, this Ministry has made efficient and effective solids management the focus of these guidelines.

The water quality impacts of discharges are controlled by approved treatment systems authorized and required by Section 24 of the Ontario Water Resources Act. The following guidelines are intended to provide direction in the design of land-based facilities. They will provide uniformity of application to farms across the province, however it is recognized that extreme situations may necessitate individual effluent quality compliance limits be established, based on

*Salmonid - Includes the rainbow and speckled trout, Atlantic salmon, and various Pacific salmon species. Does not include warm water species such as basses, walleye, bait fish, etc.

local receiving water capability. Where more stringent compliance limits may be necessary to protect a sensitive receiver, it will be the responsibility of the Ministry to define and substantiate the appropriate limits.

Guidelines for cage culture operations are under development and will be included in this publication when available.

These guidelines pertain only to Ministry of the Environment mandates. Federal, municipal and other provincial agencies may have additional approval requirements and should be contacted directly.

2.0 REQUIREMENTS

2.1 A Permit to Take Water is required by law prior to startup of the facility for all takings in excess of 50,000 litres per day (Ontario Water Resources Act, Section 20).

2.2 A Certificate of Approval (Sewage) is required by law prior to the initiation of the construction of any treatment works (Ontario Water Resources Act, Section 24).

2.3 Treatment facilities will be designed, constructed and operated with the intention to routinely achieve a concentration in the final effluent, of 5 mg/l suspended solids above the background level measured in the source water.

2.4 Treatment facilities will be designed, constructed and operated with the intention to routinely achieve a concentration of 0.05 mg/l of total phosphorus in the final effluent, except as follows:

a) Where background levels in a surface water supply exceed 0.05 mg/l, the total phosphorus Design Criterion will be no increase over the background concentration.

2.5 Compliance Limits are established as:

a) Suspended solids in the final effluent shall not exceed background (as measured on a given day in the source water) plus 10 mg/l.

b) Total phosphorus in the final effluent shall not exceed 0.1 mg/l except where the background level in a surface water supply exceeds 0.1 mg/l in which case total phosphorus in the final effluent shall not exceed the background concentration as measured on a given day in the source water.

Any exceedence of Compliance Limits shall be considered a violation of the terms and conditions of the Certificate of Approval (Sewage).

2.6 Solids removal facilities are required prior to discharge to the watercourse. Solids will be regularly removed to an off-line solids retention structure prior to land application in accordance with the appended "Criteria for Land Application of Aquaculture Cleanout Wastes".

2.7 A program of regular sampling and analysis at the expense of the operator is required. Analytical results shall be forwarded monthly to the District Officer along with a complete explanation of the circumstances of any exceedence of the Compliance Limits and of abatement measures taken to prevent a recurrence.

2.8 A log is required, which documents daily operations and other occurrences which may affect effluent quality (fish transfers or harvest, cleaning, major mortalities, major weather events, power outages, etc.). The log book shall be available for inspection by Ministry personnel.

2.9 A copy of the log and a report of all sample results and abatement action taken must be sent annually to the District Officer, Ministry of the Environment.

2.10 Where cleanout waste will be removed from the property for land application elsewhere, Certificates of Approval for an Organic Waste Management System and Site are required. Land applications will be as outlined in "Criteria for Land Application of Aquaculture Cleanout Wastes". (See Appendix).

3.0 RATIONALE

3.1 Solids Management

Proper design and management of an aquaculture facility will result in early settlement of solids in specific areas throughout the system and their frequent removal. Suspended and settled solids decompose quite rapidly in water to soluble forms which are not readily removed by treatment. consequently, solids should be handled gently and be completely removed from the rearing and settling facilities to an off-line retention structure with no outlet, on a frequent basis. Vacuuming is one effective method of cleaning which minimizes both the disturbance of settled solids and the volume of cleanout wastewater requiring storage in the retention structure.

The appropriate cleanout frequency will be as required to satisfy the effluent limits, but is expected to be

approximately twice weekly. To enable and facilitate cleaning and to prevent contamination of groundwater, the Ministry is suggesting that all rearing, settling and waste retention facilities be lined with a firm, non-permeable surface, such as concrete or metal. The use of unlined ponds is strongly discouraged due to difficulties in cleaning and resultant poor effluent quality.

Cleanout waste utilization methods should be in agreement with the general principles of the appended "Criteria for Land Application of Aquaculture Cleanout Wastes". Alternative disposal methods will be evaluated on a case-by-case basis. Transport of the cleanout wastes for utilization off the proprietor's property requires an additional Certificate of Approval for an Organic Waste Management System, application for which may be made through the Ministry's District Office.

It is the opinion of the Ministry that by effective solids management, phosphorus and other waste components will also be controlled.

3.2 Physical Facilities

Water use at aquaculture facilities generally falls into one of two categories: flow through (single pass) or recirculating. A variety of rearing systems are in use in Ontario, generally including some combination of rectangular raceways, circular tanks or ponds. While the Ministry is not prepared to dictate requirements for rearing structures, their design should be developed with effluent requirements in mind. As mentioned in Solids Management (3.1 above), settlement of solids should be promoted in specific areas (e.g. screened sumps in raceways, level controls on circular tanks, pre-settling before recirculating, etc.) throughout the system and these areas should be thoroughly cleaned on a frequent basis.

All water from the rearing facilities should pass through a solids removal facility to achieve effluent limits prior to discharge. The solids removal facility must be engineered to ensure proper performance (good distribution of flow, minimal turbulence, minimal resuspension of settled material, sized and proportioned to suit effluent flow rate, ease of cleanout, etc.). In this regard, the Ministry suggests the system be designed by a consultant competent in aquaculture design.

The retention structure shall be of sufficient size to contain all cleanout waste from all settlement areas including the final settling facility throughout the period of frost (approximately December 1 to March 31) during which time no land application is allowed. The latter requirement is due to the fact that, if applied to land in winter, the wastes would remain on the surface of the frozen ground and

could run off to the nearest stream at times of snowmelt or rain. During the frost-free period of the year (approximately April 1 to November 30) the cleanout wastes may be applied to croplands at appropriate times.

3.3 Monitoring Program

A program to monitor compliance of the operation of the aquaculture facility with conditions of the Certificate of Approval (Sewage) will in general require samples from the source water and the final effluent.

In most cases where no background contamination of the source water exists, its monitoring can be reduced or discontinued once stable quality is documented. Where effluent limits are set relative to background levels, monitoring of the source water would be needed as a basis to establish the effluent limit. The Ministry's ultimate interest is in environmental protection.

Most facilities with year-round production and harvest should be sampled monthly. Operations with distinct peaks of production should be sampled weekly during the periods of peak production.

Results of the first year of monitoring for all facilities will be reviewed and the methods, frequency and location of sampling and testing, as well as reporting requirements may be subject to alteration as required by the District Officer.

The Ministry may inspect facilities from time to time to verify adherence to all conditions of the Certificate of Approval.

4.0 APPLICATION AND AMENDMENT OF GUIDELINES

These guidelines have been developed by the Ministry of the Environment Aquaculture Committee on the basis of direct Ministry of the Environment experience and knowledge of the available literature on wastewater treatment in aquaculture and in consultation with representatives of the aquaculture industry in Ontario. As research continues and additional experience is gained, revisions to these guidelines may be made from time to time. Comments on, or formal proposals to amend, these guidelines should be addressed directly to:

Director
Water Resources Branch
Attention: MOE Aquaculture Committee
Ministry of the Environment
1 St. Clair Ave. W.
Toronto, Ontario
M4V 1K6

Appendix I: Criteria* for Land Application of Aquaculture Clean-Out Wastes

1.0 Under the Environmental Protection Act and the Ontario Water Resources Act all spreading sites must be certified by the Ministry of the Environment. Prior to site certification and use, factors such as site location, land and soil characteristics and proposed site management methods must be assessed to minimize potential hazards to surface watercourses, groundwater, wells and residences.

2.0 Application rates not more than 1.3 cm depth or 130 cubic metres per hectare of clean-out wastes may be applied at one time. There may be no subsequent application until the preceding application has dried.

3.0 Separation Distances

3.1 Surface Watercourses

For the purpose of these Guidelines, a surface watercourse is defined as a natural or established surface watercourse or an open municipal drain along which water flows on a regular basis.

The minimum distance between the spreading site and a surface watercourse should normally be determined from Table 1 which takes into account land slope and soil permeability. If clean-out wastes are incorporated into the soil at the time of application, it may be applied closer to a watercourse than indicated in the Table. However, it should not be applied within 10 metres of any watercourses or body of water.

Ministry of the Environment staff will advise on separation distances from bodies of water or drainage channels other than surface watercourses as defined above.

3.2 Groundwater

The ground water table should not be less than 0.9 meters below the soil surface at the time of clean-out waste application.

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* The criteria listed in this appendix have been derived from the publication "Guidelines for Sewage Sludge Utilization on Agricultural Lands", Ontario Ministries of Agriculture and Food, Environment, and Health, January, 1986.

3.3 Bedrock

Clean-out waste application should not normally be allowed where the soil overlying bedrock is less than 1.5 metres thick. Under special circumstances, and based on site-specific information which demonstrates that the risk of ground and surface water contamination is minimal, sites with a lesser thickness of soil may be used.

3.4 Residence

According to Ontario Regulation 309, the minimum separation distances from residences in residential areas and individual residences not in residential areas shall be 1500 feet (450 metres) and 300 feet (90 metres) respectively. If the Regulation should, in the future, permit it and where there is little cause for concern, these distances may be reduced. In no case should they be less than 50 metres and 25 metres respectively.

3.5 Water Wells

According to Ontario Regulation 309, the minimum separation distance from any water well shall be 300 feet (90 metres). If the Regulation should, in the future, permit it and where there is little cause for concern, this distance may be reduced. In no case should it be less than 15 metres.

4.0 Snow Covered and Frozen Ground

To minimize runoff, clean-out wastes should not be spread on frozen or ice covered soil. The period of frost is approximately December 1 to March 31.

5.0 Record Keeping

Records are to be kept of the location of all fields receiving clean-out wastes, the volume of clean-out wastes applied to each field and the date of application.

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Table 1

Minimum Distances to Watercourses

Maximum Sustained Slope	Soil Permeability *	Distance (Metres)
0 to 3%	Rapid to Moderately Rapid	60
	Moderate to Slow	120
3 to 6%	Rapid to Moderately Rapid	120
	Moderate to Slow	240
6 to 9%	Rapid to Moderately Rapid	180
	Moderate to Slow	Not Permitted
Greater than 9%	All permeabilities	Not Permitted

* Soil permeability shall be determined in accordance with the requirements of the Ministry of Agriculture and Food's publication entitled "Drainage Guide for Ontario". The type of soil should be determined with the aid of County Soil Maps, which are available from that Ministry.

NOTES: 1. Spreading should be suspended when run-off is expected.